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Undergraduate Research in Kentucky: Biological Sciences

Introduction

Undergraduate education in the biological sciences has changed dramatically during the last 20 years. With the call for greater linkages between teaching and research (National Research Council 1996) and the need for improved teaching of science process, colleges and universities in Kentucky responded with a variety of approaches and courses all designed to get students doing biology rather than simply learning about the discipline. Indeed, what was once considered to be solely within the domain of graduate education is now rapidly becoming a standard component of the undergraduate experience.

Granted, undergraduate research has long been a tradition in the small liberal arts colleges. Only recently have the state colleges and universities come to the conclusion that yes, undergraduate students are capable of conducting innovative research, and yes, this research is of value in the educational process. Not surprisingly though, the means whereby small colleges, regional universities, and research universities achieve more undergraduate research are many and varied.

It is the purpose of this special section of the *Journal of the Kentucky Academy of Science* to examine the various approaches that have been taken to facilitate undergraduate research in Kentucky, to cite difficulties involved in this curricular transition, and to point out synergisms that might develop in the future among various educational institutions. Getting undergraduates to appreciate the enterprise of science, to think as scientists, and to work like scientists is not easy. I hope, though, that the different programmatic features described in this series of articles will be of some value as teachers in Kentucky colleges and universities strive to bring more research opportunities to their students.

Sixteen Kentucky colleges and universities were invited to contribute to this special issue: Asbury College, Berea College, Campbellsville College, Centre College, Cumberland College, Eastern Kentucky University, Georgetown College, Kentucky State University, Kentucky Wesleyan College, Morehead State University, Murray State University, Northern Kentucky University, Thomas More College, University of Kentucky, University of Louisville, and Western Kentucky University. Some of these were unable to participate.

James O. Luken
Department of Biological Sciences
Northern Kentucky University
Highland Heights, KY 41099

LITERATURE CITED

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Undergraduate Research in Kentucky: Biological Sciences

A Program for Facilitating Undergraduate Research in Biology

Jerry W. Warner

Department of Biological Sciences, Northern Kentucky University, Highland Heights, Kentucky 41099-0400

ABSTRACT

During the year-long introductory course for biology majors at Northern Kentucky University, students are exposed to research interests of faculty and are required to conduct a series of laboratories of an investigative nature. A sophomore course in information resources helps them develop the skills they need for conducting literature research. As juniors they are encouraged to take courses in biological techniques that they can then apply to directed research projects. As seniors they must present two seminars that can be based on their research. They are also encouraged to present their research results at meetings of the Kentucky Academy of Science, Beta Beta Beta, or other appropriate organizations.

INTRODUCTION

The Department of Biological Sciences at Northern Kentucky University (NKU) has about 425 undergraduate majors. About half begin as declared majors in general biology or teacher education in biology. The others, at least initially, are pre-professionals of one type or another. Because the professional programs they are working toward are very selective, many will not be successful in getting into the program of their choice and will remain at NKU to finish a degree in biology. Others, once they gain some insight into career opportunities available to biologists, will change their major to general biology early in their first year. Still others will change to a major not related to the biological sciences.

The faculty of the department consists of 14 full-timers plus myself. Although the primary mission of NKU has always been undergraduate instruction, members of the faculty are encouraged to remain active scholars. Over the years, many of the faculty have maintained ongoing research programs and most of these have a history of involving students in their research.

When I became department chair in 1990, there was evidence of a division in the faculty along the lines of those who were involved in research and those who were not. One of my first endeavors was to look for ways to overcome this problem and bring the faculty together to work toward common goals that would benefit students and make us a much stronger department. This was accomplished in part by encouraging and making it possible for all faculty to participate in some sort of scholarly activity. In addition to this new emphasis, we began to explore curricular changes that were affordable and that would make research an integral part of each major's degree program.

STEPS FOR ASSURING SUCCESS

The process that ensued has been of an evolutionary nature. We recognized from the start that we already had some basic components in place that would be useful in this transition. We also realized that these components might require some alterations and that we would need to add other important parts. We knew that if we were to be successful in having undergraduate students do meaningful research, we would need to introduce them to scientific research and the research process early during their first year of college and that we would need to build on that foundation each succeeding year.

The components, already in place were as follows:

BIO 150 & BIO 151 Introduction to Biology I & II (10 semester hours; required courses)

BIO 240 Library Resources in Biological Sciences (1 semester hour; required course)

BIO 401 Seminar (1 semester hour; required course)

BIO 496 Independent Study (1–3 semester hours each, up to a total of 6 semester hours; elective course)

BIO 497 Techniques of the Biological Sciences (1–2 semester hours each, up to a total of 4 semester hours; elective course)

Although we had these basic components in place we did not have a clear plan of how to best use them to assure a meaningful research experience for our students. We realized that the sequence of courses was important and that, while the sequence was appropriate for some students, much was being left to chance. Therefore, we set about to restructure our curriculum in a logical way that would stimulate interest in undergraduate research.

Over a period of several years we made changes that we believe have made notable improvements. These changes are designed to introduce biology majors to research. Students are led step-by-step to the point where they are doing research, making presentations, and, by the time they graduate, publishing scientific papers (with a faculty member).

The first thing we did was to reevaluate the way we deliver our introductory courses (BIO 150 & BIO 151). After meticulous examination we changed the way lecture instruction is provided, thoroughly revised the laboratory experience, and added a new component. The details are as follows.

Lecture

For almost 20 years a single instructor had sole responsibility for two sections of lecture per semester. BIO 150 & BIO 151 had become identified as his course rather than the department's course. In the early 1990s we changed this by having another instructor work with the established professor. Teaching responsibility was divided so that each taught about one-half of the course. In following semesters more faculty members became involved. The original professor was relieved of having to teach these courses on a continual basis and, instead, became one of several course instructors. We now have six faculty members who have taught BIO 150 & BIO 151 in various team combinations. This restructuring has brought a variety of faculty into contact with our majors during their critical first year, and it has resulted in faculty working closely with one another in the classroom.

Laboratory

Prior to this revision, we used a commercially available laboratory manual that was designed to have students learn a lot of factual material about biology. While much of it was good-to-know information, students were not required to use the scientific process or to develop critical thinking skills. In preparation for this new approach, laboratory time was restructured from two 2-hour sessions per week to one, 3-hour session per week. This larger block of time better accommodates the investigative approach that was installed. Faculty teaching the laboratories wrote new exercises that require students to collect data, to analyze it using computers, and to draw conclusions about their findings. This process enables us to achieve our goal of having new majors learn about the research process by doing research.

Recitation

This new course component is designed to provide beginning biology majors an orientation to the discipline. It meets once a week for 1 hour. Departmental faculty come as guests to talk about the upper-level courses they teach and the research they do. Students are provided an opportunity to get to know faculty at an early stage. One requirement of recitation is that students are assigned scientific papers to read and respond to. They become familiar with different types of publications (i.e., review articles, primary articles, popular articles, etc.) and the appropriate use of each.

Following completion of BIO 150 & BIO 151, biology majors must take BIO 240 Information Resources in Biological Sciences as soon as possible. This course, formerly called Library Resources in Biological Sciences, has changed as the Steely Library has incorporated new methods of information retrieval such as on-line searches, use of the internet, etc. Successful completion of this course provides students with the basic skills they require to perform a search of the literature.

One of the important additions that we made to our curriculum was the establishment of a new, required course, BIO 390 Principles of Research. This course was added as a vehicle for teaching modern scientific methodology including problem selection, experimen-

tal design, survey of scientific literature, and development of a research proposal. Students are to take BIO 390 as soon as they complete BIO 240, that is, in the spring semester of their sophomore year or in the junior year. One immediate outcome of this course is that some students use their proposals, with some elaboration, to successfully apply for research grants from sources such as Beta Beta Beta and Sigma Xi as well as for summer research grants available from NKU.

Following completion of BIO 390 (and sometimes concurrent with it) majors are encouraged to register for BIO 397 Techniques of the Biological Sciences. Students in BIO 397 work directly with a faculty member to learn basic techniques necessary for conducting research in a specific area. This is not a required course and it may not be necessary for all students who want to do research.

The next step is to actually get involved in a research project with a faculty member. Students can do this by registering for BIO 496 Directed Research (an optional course). This involves the student working with a faculty member on some aspect of that faculty member's ongoing research. Students are encouraged to present the results of their research effort at a scientific meeting such as that of the Kentucky Academy of Science, national or regional meetings of Beta Beta Beta, or others as appropriate. This research will often result in a publication with the student as co-author with the faculty member.

All biology majors are required to take BIO 401 Seminar usually in their senior year. If they have followed the route as above described, seminar is rather anticlimactic. They may base their presentations on the research they have done. Those who do not follow this route must select topics, do thorough literature searches, and give presentations based on the literature rather than on their original research.

RESULTS

At the 1996 annual meetings of the Kentucky Academy of Science 69 undergraduate students from throughout the state entered the undergraduate research competition. Of these the NKU Department of Biological Sciences had 10 students who made presentations and four others who jointly presented a poster. Five of these students were recipients of awards as follows: Botany and Microbiology section, 2nd and 3rd place winners; Cellular and Molecular Biology section, 1st place winner (co-winner); Zoology and Entomology section, 2nd place winner; and Undergraduate Poster Competition, 1st place winner; This is an impressive showing especially when you consider that undergraduate presenters from our Department of Biological Sciences won recognition in every section in which they participated. No other single department in the state did as well.

In December 1996 three of our students were awarded research grants totaling $1999 from the Beta Beta Beta Research Foundation (national biology honor society).

A fourth student received a $600 Grant-in-Aid of Research from Sigma Xi to support research in Costa Rica on a hybrid of the genus *Heliconia.* As a result of work in summer 1996 he was invited to spend three weeks in summer 1997 at the National Museum of Natural History of the Smithsonian Institution in Washington, DC.

The 6 February 1997 issue of *USA Today* listed the results of its annual Academic All-Stars competition. One of the honorable mention winners was a biology major from Northern Kentucky University who was selected as a result of his work on cancer research. This student was the only undergraduate selected from Kentucky at any level. As an Honorable Mention Winner, he was in good company with students from such schools as Brandeis, Harvard, Notre Dame, and Princeton.

In April 1997 two of our students attended the annual meetings of the National Conference on Undergraduate Research in Austin, Texas, where they gave presentations based on their research. During this same time, five other students traveled to Furman University to make presentations on their research at the regional meetings of Beta Beta Beta.

Three of our majors received Greaves Undergraduate Summer Research Stipends of $2500 plus $500 for supplies for summer 1997. Five such awards, based on competitive research proposals submitted by the students, were made by NKU.

FUNDING STRATEGIES

Funding for the support of these activities came from several sources as follows: (1) small

amount from the operating budget of the Department of Biological Sciences; (2) Small amount from faculty grants of mentors; (3) grants awarded to students from sources such as Sigma Xi and Beta Beta Beta; (4) Greaves Summer Research Stipends provided by NKU from an endowment for support of the sciences; and (5) considerable sum from alumni donations (amounting to several thousand dollars per year that goes to a departmental foundation account used for supplies, travel expenses of students to meetings, etc.).

CONCLUSIONS

Although Northern Kentucky University is primarily an undergraduate institution, the faculty of the Department of Biological Sciences strongly believes that research should be an integral part of the curriculum. To develop an environment in which our students welcome research activity as a basic component of their education, we begin during the freshman year to expose them to research and its importance. The plan outlined here has already resulted in impressive accomplishments. We fully expect that student interest in research will continue to grow and that the benefits to our students will be significant. Although the number of majors in relation to the number of faculty and the available facilities currently prevents us from requiring research participation as a graduation requirement, we hope to move in that direction. It is important to note that these successes have been possible because of dedicated, enthusiastic faculty members being willing to put in many extra hours.

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Undergraduate Research in Kentucky: Biological Sciences

Using Water Quality Monitoring as a University-Level Teaching Tool

Brian C. Reeder

Department of Biological and Environmental Sciences, Morehead State University, Morehead, Kentucky 40351

ABSTRACT

Juniors and seniors at Morehead State University gathered water quality data for a variety of monitoring projects from 1994 to 1997. This research experience indicated that intermediate-level students benefitted most. These students were more attentive to detail in lab than normal, and the majority of the data collected was reliable and accurate, as long as the analysis techniques were simple. Most students were less reliable at gathering data that required more complex procedures, such as measuring total phosphorus and nitrogen. Although student involvement increases the supply costs, the educational benefits suggest government/university collaborations of this type can be beneficial for all participants.

INTRODUCTION

Students learn more about the scientific method by being actively engaged in research than they do by reading about it. Undergraduate students gain confidence, skill, and an appreciation of the scientific method by being involved in research projects (Lanza and Smith 1988; Lord 1989). Although the virtues of student involvement in scientific research are well known, most projects rely on academically exceptional students, usually working one-on-one with a researcher.

Over the last 3 years I have engaged in the experiment of using large (20 to 40 students) undergraduate laboratory classes to monitor water quality for various government agencies. These projects encouraged students to think critically (i.e., gather information, process information, evaluate evidence, draw conclusions) in an active learning environment. My goal was to use the ideals of scientific inquiry (based on logic and the evaluation of evidence) to increase student appreciation and understanding of water analysis, which they had previously thought was complicated, boring, and sometimes even dangerous. An additional goal was for students to gain an understanding and appreciation of how new knowledge is obtained.

Students were asked to learn both content and process. Although most professors agree that learning the scientific process is important, few integrate class research, which is one of the best ways to teach how knowledge is gained (Foster 1989; Janners 1988; Postlethwait 1980). My definitions of active learning and critical thinking are more traditional than some current education experts espouse. Ironically, many contemporary proponents of "critical thinking" fail to use the scientific method when making claims of success (Morgan 1995). Similarly, "active learning" is not unknown to those of us who have been immersed in laboratory experiences throughout our educational careers.

Field activities are not prevalent at the postsecondary level, despite the evidence that students find field biology exciting and engaging (Hall 1996). Research suggests that field experiences allow students to concentrate on process skills in a non-distractive environment and encourages camaraderie among students as well as student-professor interactions (Hall 1996; Wheater 1989). It has been suggested that student participation in monitoring projects enhances student interest and learning (Zaimi et al. 1994)

Unlike a pre-prepared laboratory exercise, the projects used in this study enabled the students to engage in research that could have consequences on how water resources in the region would be managed. The merging of learning and performance goals should motivate students and enhance learning success (Dweck 1986). Additionally, since the students' water analyses could have important consequences (beyond performing for a grade), material retention should increase (Carey 1986). Based upon the theory that a field research experience would increase learning,

this study endeavors to use a large number of undergraduate students for environmental monitoring projects and to discover benefits and pitfalls of the educational experience.

MATERIALS AND METHODS

Participants included all the students taking four ecology courses (required of all biology majors, including pre-professional students and environmental science majors) and two limnology courses (required of all environmental science majors; an elective for biology majors). Over 120 undergraduate students, with various interests and abilities, participated in the projects. The average ACT composite score for the students involved was 23.2—better than the average MSU student (1992 to 96 mean composite ACT = 19.8); and the national mean for undergraduates (1992–1996 composite national norm = 21.4). The minimum prerequisites for the courses were junior or greater rank, college algebra, and eight semester hours of college chemistry, botany, and zoology; therefore all the students were familiar with the chemical and biological equipment that would be used for their research.

Three water quality monitoring projects involved students: (1) appraising local streams for the Health Department during 1994–1995 to make recommendation on sewage upgrades; (2) assessing the trophic status and water quality of Grayson Lake during the 1995–1997 growing seasons to determine the effects of different management schemes; and (3) monitoring the effects of different types of fertilizer on ponds at the Minor Clark Fish Hatchery during spring 1997.

Before working on the research project, students had two or three 2-hour lab periods during which they practiced field sampling and the chemical analysis of soluble reactive phosphate (SRP), nitrate, nitrite, and ammonia. Limnology students also learned how to measure total phosphorus (TP), total Kjeldahl nitrogen (TKN), total suspended solids, and chlorophyll a. Students used standard methods (APHA 1985) or the simplified Hach equivalents (Hach Company 1994). All students were required to take field water samples and become familiar with operation and calibration of field instruments to measure dissolved oxygen, pH, conductivity, and Secchi depth. Students always worked in groups of two to five. After all the samples were analyzed by the student groups, I or a graduate student repeated the analyses to check for reliability.

After the project, each student was required to write a report (including results and statistical analysis) using a scientific format (i.e., introduction, materials and methods, results, recommendations, amd literature cited) that was suitable for submission to the funding agency. Students knew their reports would not only be graded but possibly given to the agency to aid in decision-making. Reports were generally worth about 20% of their lab grade; lab grades were worth about 1/3 of their final grade for the course.

Student outputs were analyzed to see if there was any learning enhancement for a particular group. I compared their overall ACT score to their scores on both the laboratory project and their final score in the class. Data included all the students involved in the project for which all scores were available (ACTs were not on file for some transfer students). Since more than 30 students took both ecology and limnology, I included their scores from only the first time they did the project so there would be no bias toward those repeating the assignments and activities. Graduate students, too, were removed from the data set.

RESULTS

As most people who have taught or taken laboratory courses know, one of the common problems creating poor results is that many students try to "cookbook" their way through procedures in the fastest possible manner. This also usually results in students not understanding the underlying assumptions behind much of what they did or how the results apply to the hypothesis tested. In contrast, the laboratory atmosphere during most of our projects was extraordinarily dynamic.

Compared with other labs, students tended to be much more attentive to details and much more concerned with doing procedures correctly. For example, it was not uncommon for a student to question if or how they may have done something wrong and to repeat procedures until they were satisfied with the outcomes. Students recognized the lab procedures when questioned about them on exams and were able to interpret results with relative

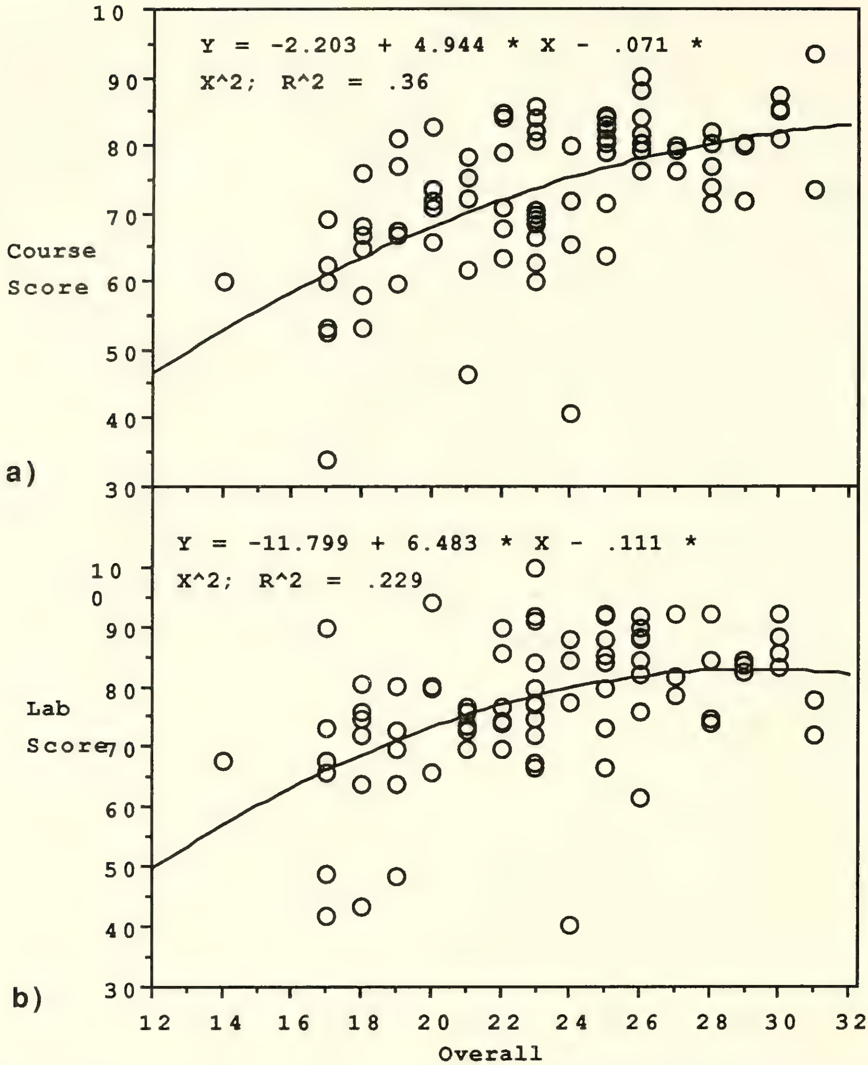

Figure 1. Relationship between overall ACT scores and student performance in water monitoring projects at Morehead State University. Best-fit of second-order regressions between ACT and (a) final score in the course and (b) score on a research report based upon the research activity.

accuracy in reports. I assumed this attention to detail was because the students knew that their data were going to be used for a management decision in the region.

A comparison of ACT scores to their performance on their research reports showed that students with high ACT scores tended to perform better than those with low ACT scores (Figure 1). It is interesting to look at the performance by mid-range and high-performing students (arbitrarily chosen as students with a composite ACT > 19). Mid-level students (abitrarily chosen as students with ACT scores 20 to 26) achieved scores just as high or higher than the 'A' students when given a problem-solving activity. A linear regression slope of ACT vs. lab score for students with ACT composite scores greater than 19 is only 0.72 (correlation r = 0.22; n = 65). The slope for these same students vs. their final score in the course is 1.28 (correlation r = 0.41; n = 65), showing that mid-range students performed better on the research project than on other course projects and exams.

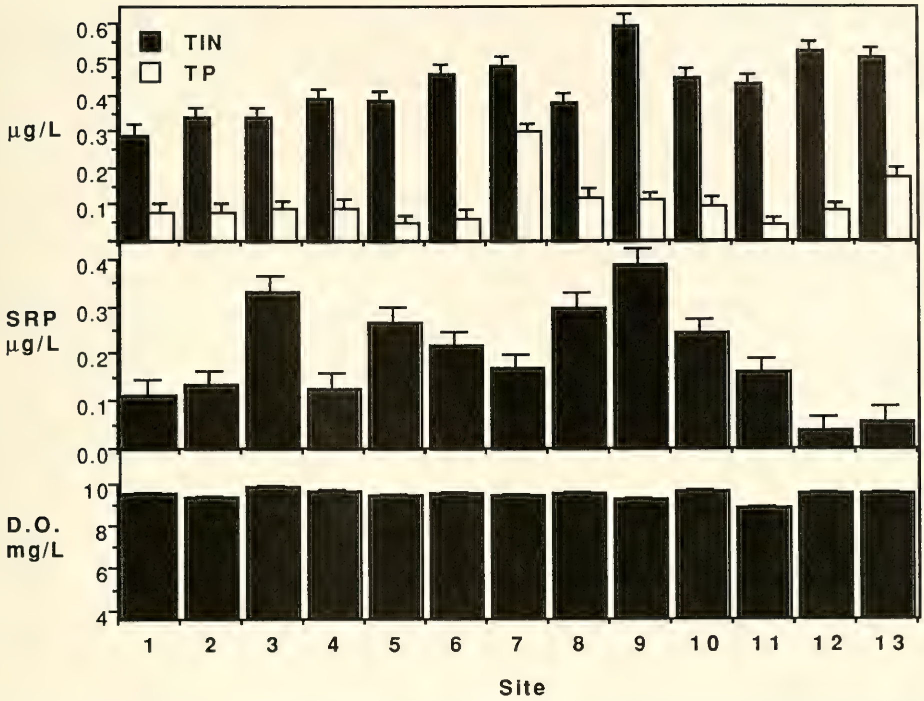

Figure 2. Results from water monitoring projects at Morehead State University. Student measurements of dissolved oxygen (D.O.), total phosphorus (TP), soluble reactive phosphorus (SRP), and total inorganic nitrogen (TIN) concentrations in 13 sites along Triplett Creek and its tributaries from Sep 1994 to Aug 1995. Error bars represent one standard deviation.

A concern when using students for monitoring and research is whether the data they collect are reliable and accurate. Most students were able to perform well on simple tasks, and data from different lab groups usually agreed fairly well (Figure 2). Measurements that required the use of electronic meters (e.g., Hydrolab, YSI D.O., conductivity meters, and pH meters) or a Secchi disk in the field were always accurate. In the lab, students were equally competent with spectrophotometric measurements using Hach Accuvac ampules or 1–2 step chemical procedures.

On more complex analyses, such at TP and TKN digestions, or nitrate using cadmium reduction columns, students were much less effective at obtaining accurate information. When the data were incorrect, values often deviated from standards by an order of magnitude; these problems could usually be traced to contamination, errors during sampling, or errors in specific procedures.

Not all classes were able to perform even the simple tasks effectively; the limnology class from spring semester 1997 had a greater than 40% failure rate in lab work. This class was less attentive to detail and more cavalier in attitudes toward the project than previous classes.

DISCUSSION

Lanza and Smith (1988) suggested that the success of undergraduate research projects should be gauged by the quality of the research and the amount of student growth. Our projects were usually successful at increasing both. More importantly, the data suggest that middle-range students gained more from this experience than other students did. Poor students did not increase in performance; no harm was done to successful students. This could be an important area to explore with a more controlled study.

From the standpoint of the instructor, running a laboratory as part of a monitoring pro-

ject increases the time commitment, since quality must be ensured. However, college professors of ecology and limnology routinely gather vast amounts of field data in teaching students the techniques of collecting and analyzing ecological information. It only takes a bit more effort to make this data gathering "real."

The obvious educational advantage of this approach is that students will tend to be much more attentive and motivated than when they are performing less consequential analyses. Cheating should most likely be reduced since the emphasis is on solving a relevant problem rather than simply getting a number to put in a box. Lord (1989) even suggested that professors who have lost their love of exploration as a result of teaching the same course for many years may rediscover the excitement of learning when they get undergraduate students involved in research.

There are important considerations for taking on a project like this. To do the checks, train the students, and allow for multiple groups to analyze the same samples, we performed at least four times as many tests as we would have if monitoring under normal conditions. Consequently our material and supply costs increased about four-fold. To some extent these financial costs were offset (i.e., I would have run some of these tests as part of the labs for teaching purposes under normal circumstances). Since water analysis labs are included in all the major limnology ad ecology laboratory manuals, I assume many other professors would be in a similar situation. It could be assumed that I simply took money that would be "wasted" and put it to a more practical use (Zaimi et al. 1994).

This study also has implications for the use of citizens in water quality monitoring. Like our students, citizens and school children are often highly motivated to monitor lakes and streams. It should be noted that our students sometimes failed at relatively simple tasks, although their training in chemistry and using instrumentation was far in excess of average persons. Furthermore, some of my students' errors occurred due to contamination of sample containers in the field. Citizen volunteers usually limit the water analysis they perform to fairly simple techniques and measurements, and they send water and chlorophyll filters off to a lab to be analyzed (Ely 1997; Simpson 1991). Our study suggests that complex chemical analyses would be difficult for citizens to perform.

Although the main tenet of "active learning," which many of us in the sciences call "lab," is to foster understanding and comprehension of material by using problem-solving activities, this type of attentiveness is not common for the majority of students in most traditional labs. Although it is a subjective observation, I feel that when students are given the opportunity to confront a real problem in their geographic area, combined with knowing that their results are important (and may be submitted to a government agency), it greatly enhances the learning experience. Additionally, our environmental science majors, many of whom may eventually be employed in the Commonwealth, gain the type of "real world" experience they need to understand their chosen field. Involving students in solving community problems has been beneficial for the students, the agency, and the community.

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Undergraduate Research in Kentucky: Biological Sciences

A Summary of 25 Years of Undergraduate Research at the Thomas More College Biology Field Station: What Became of the Students?

William S. Bryant and John W. Ferner

Department of Biology, Thomas More College, Crestview Hills, Kentucky 41017

ABSTRACT

A total of 101 of the 116 students who worked as undergraduate researchers at the Thomas More College Biology Field Station from 1971 through 1996 received their bachelor's degrees. The other 15 students were still in school in 1996. This paper summarizes the post-bachelor's choices of the 101 graduates and discusses some of the reasons that over 85% of them attended graduate or professional schools.

INTRODUCTION

Carter et al. (1990) wrote that, 'Students must participate in the doing of science in both the laboratory and field.' That was the view at the center of the Thomas More College (TMC) Department of Biology's initial grant application to study microbial populations in the Ohio River (Budde et al. 1971). The grant was funded by the Cincinnati Gas and Electric Company; the base or control site for that research was the TMC Ohio River Biology Field Station near California, Campbell County, Kentucky. The station was the former Lock 35 property and was acquired by the College in 1967; it has been upgraded over the years. The Department of Biology has received grants for various research projects at the station from 1971 to the present (excluding 1993). A major stipulation of the first research grant was that undergraduate students would be involved in all areas of data collection and analysis.

Over the years, research projects at the station have focused on various aspects of the Ohio River including bacteria, phytoplankton, zooplankton, benthos, fishes, zebra mussels, water chemistry, ash drainage, thermal pollution, and impingement. The Cincinnati Gas and Electric Company has never dictated what aspects to consider for research; however, project selection generally has centered around the impact of electric power plants on the Ohio River.

A total of 116 undergraduate students have participated on the 25 projects from 1971 to 1996 (excluding 1993). Of that total, 101 students had graduated from Thomas More College by the end of summer 1996. This paper reports on the post-bachelor's career choices of those 101 graduates and discusses the role that their undergraduate research experience at the station may have played in their choices.

STUDENT SELECTION PROCESS

The selection of undergraduates for participation in the summer research projects at the station involves a number of steps. Beginning in January of each year, applications are made available to interested students. After applications have been returned by the specified date, all biology faculty members, not just those who will be involved with the research project, review the applications. The recommendation from each faculty member is considered in student selection. Students are chosen not just on the basis of academics (e.g., high grade-point average). Other factors considered are previous experience, ability to swim or handle a motor boat, courses taken, interests, personality, and grade level. We seek a mix of year levels—sophomores, juniors, and seniors—and a mix of those with previous experience to those without experience. The students selected, generally four to 10 per summer, are notified immediately. They receive a stipend plus room and board for the period of research. The base of operations is the TMC Ohio River Biology Field Station.

RESULTS

Of the 101 TMC graduates who worked as undergraduate researchers on grant-supported projects at the station between 1971 and 1996,

Table 1. A summary of the post–baccalaureate educational choices of the 101 undergraduate researchers at the Thomas More College Biology Field Station from 1971–1996.

Graduate school (M.S. and/or Ph.D. programs)	47.5%
Medical school and related (M.D., D.O., D.P.M., D.V.M., D.D.S., D.C., Pharmacy, Nursing, Med. Tech)	34.7%
Law (J.D.)	3.0%
Other (M.B.A., Theology)	4.0%
None (Have not pursued a formal educational program at this time)	10.9%

58 were male and 43 were female. Of the 101, eighty-six (85.5%) continued their education beyond the bachelor's degree.

A majority of former undergraduate researchers, 47.5%, have attended graduate school, 34.7% continued in a medical field, 3.0% in law, 4.0% in other areas (e.g., business, theology); 10.9% have not pursued further formal education (Table 1). Five of those who, as of yet, have not pursued further education degrees are involved in environmental work or research. Thirty-nine students (38.6%) have completed or are in terminal degree programs. Currently, 43 (42.6%) of the former undergraduate researchers are working in an environmental field. That number does not include two attorneys who are practicing environmental law.

DISCUSSION

Two-thirds of the students attending liberal arts colleges plan to attend either graduate or medical school (Carter et al. 1990). Over the past 10 years at TMC, 20% of the graduates from all majors entered graduate or professional school; however, a much larger number—71.2%—of biology graduates did so. Since over 85% of students who participated as undergraduates in the Ohio River research projects have continued their education, we felt that the undergraduate research experience may have had a positive influence regarding their decisions; field station participants entered graduate or professional schools at significantly higher rates than biology majors (z test; 0.05 level). Although we have not systematically sampled each former undergraduate researcher, we did question a number about their decisions. We also questioned and discussed this with faculty members.

Some of the factors that seem to have influenced our former undergraduate researchers in terms of their career choices or in their decision to continue their education are discussed below.

1. Students who participated in research can see science as an active process, one that is continued beyond the classroom. They were involved in data collection and analysis, equipment repair, and maintenance—not just in note taking and memorization of facts. Seago (1992) noted the importance of research and discovery to the cognitive process.

2. A close working relationship between students and faculty develops at the station. The small number of students encourages cooperation. These students see faculty in a different light than those whose only contact with faculty is through lecture courses. Students see that faculty enjoy their work, especially research. Seymour and Hewitt (1994) found that students who condemned faculty obsession with research changed their ideas dramatically when they were allowed to observe or participate in that research. The few students who had this experience liked the pleasant and open way in which faculty treated undergraduates in research relationships, compared with their apparent indifference to them in a teaching context. Five of the eight TMC faculty who have worked on summer research grants at the station are still on the TMC faculty; students recognize the importance of this continuity.

3. Students build confidence and learn from practice rather than from theory only. The attitude of the student is important (Seago 1992). Doing hands-on activities, using taxonomic keys, and learning from other students who have had previous work experience at the station are vitally important. The mixing of year levels at the station is important, too, as students learn from each other.

4. Students are given a stipend for their research participation. This is an incentive to earn tuition money for next year in a summer

research project. The students may also choose to live at the station in dorm-style housing and to receive free board. Some students have also received academic credit for a portion of their research work.

5. Because the research is funded by industry, students begin to see the importance of environmental work to industry. Students also learn how industry works to achieve environmental compliance.

6. The time that the research is ongoing, i.e., summers for 8 to 10 weeks, is generally a time when students are not in school. They do not have to concentrate on other courses but can devote their entire energies to their projects. The students also learn to handle a motor boat, electro-shocking equipment, water chemistry tests, etc. And they have some free time to enjoy the water.

7. All participants are given joint authorship of the final report submitted to the sponsoring industry. This provides students with a significant addition to their résumés. Often this type of documented research may give students an advantage as they apply for graduate/professional schools or for jobs. When students put the research findings in written form for others to read, the act of communication forces students to produce a better perspective of the process and the project (Seago 1992).

8. In recent years some of the students have presented portions of their research results at the Argonne Undergraduate Research Symposium in Chicago. Science favors the prepared mind (Bruner 1973), and learning to discuss and conduct research is a major part of developing that prepared mind (Seago 1992).

A number of other factors may also enter into the equations that influence students to continue their education. Preparing this paper has brought this to our attention. We hope to analyze these factors systematically in the future by surveying all of the former undergraduate researchers who have worked on summer research projects at the TMC Biology Field Station.

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Undergraduate Research in Biology: A Developmental Approach

Robert W. Kingsolver and David F. Oetinger

Department of Biology, Kentucky Wesleyan College, Owensboro, Kentucky 42302-1039

ABSTRACT

Undergraduate research can be improved by introducing skills and concepts incrementally over a 4-year college biology curriculum. Extensive firsthand experience with biological systems, along with a formal introduction to scientific practices and professions early in a student's education, facilitates applications of ideas and techniques encountered in subsequent course work. Integration of learning, both within the sciences and with other disciplines, is essential. Gradual transfer of responsibility for laboratory study to the student develops the ability to conduct quality research, demonstrated by an independent project and a senior seminar presentation.

EDUCATIONAL PHILOSOPHY

A distinguishing feature of liberal arts education at 4-year colleges is that the unit of instruction is not the course, or even the major, but the entire undergraduate curriculum. Frequent contact between faculty from different disciplines facilitates coordinated educational effort, and continuity of the student–faculty relationship over 4 years allows faculty to approach complex educational objectives incrementally, by building one experience on another over the student's college career. This developmental approach to undergraduate education holds many advantages for the student, but it is especially effective in teaching and coordinating the array of concepts and skills required to conduct meaningful scientific research.

Scientists often refer to their research as an art form rather than a reproducible method (Thomas 1974). While it is true that a researcher's creativity and insight cannot be captured in matrices of curricular objectives, we believe that the challenge in teaching students to conduct research lies not in its indefinable nature but in its complexity. Like swimming or flying a plane, research is not a single skill but a suite of attitudes and abilities that must be developed one at a time. The 'sink or swim' model with which neophytes are frequently introduced to research throws the entire challenge at them in one assignment, typically demanding a research report or science fair project as the only measure of success and leaving them to negotiate dozens of difficult steps in the process as best they can. The unfortunate result is polarization of student attitudes; those who survive are exhilarated, but many are left bewildered and alienated by the scientific process.

Among the skills and concepts prerequisite for successful undergraduate research are (1) observing natural phenomena, with the understanding that scientific concepts are ultimately derived from nature; (2) finding bibliographic sources, with the understanding that scientists build on the work of others; (3) reading scientific papers, with the understanding that published material is peer-reviewed but not infallible; (4) generating testable hypotheses, with an understanding of the appropriate scope of a student project; (5) designing experimental methods, with an understanding of the importance of controls and replicates; (6) developing a research proposal, with an understanding of the limits and sources of funding; (7) performing experiments, with an understanding of safety, cooperation, and ethical treatment of research subjects; (8) recording data, with an understanding of the importance of honesty and accuracy; (9) interpreting results, with an understanding of the appropriate statistical methods; (10) presenting the work in written, oral, and graphic formats, with an understanding of the power of effective communication; (11) critiquing the work of others, with an understanding that ideas, not colleagues, are subject to rejection; and (12) learning from mistakes, with the understanding that experimentalists learn more from surprising failure than from anticipated success.

Although these steps are listed in order of their application, they are not necessarily mastered in this sequence. 'Ontogeny does not recapitulate phylogeny' in the development of scientists. The research proposal, for example, is a primary step for professionals but not an ideal introductory challenge for students. There are also good reasons to teach reading and writing of research papers as a unit in biology classes, even though these tasks are separated in the research cycle.

Kentucky Wesleyan College's biology program expects every undergraduate student to master research skills and conduct research as a requirement for graduation. We therefore avoid the common practice of selecting a few talented students and placing them with research mentors as if they were already in graduate school. Mentoring of selected students provides valuable experience for participants (e.g., Cortinas et al. 1996; Rodriguez and West 1995), but this strategy does not serve the majority of undergraduates. It also tends to engage students in the collection of data but not in the earlier stages of hypothesis forming and research design. A simple project of the student's own invention can be more heuristically valuable than performing a pre-determined role in a more sophisticated project (Lanza 1988; Soprano 1990).

We have also resisted the common practice of denying undergraduate research experience to pre-medical and other allied health pre-professionals. While these students may not intend to pursue research careers, we believe that they should be trained in the mechanisms of science. In short, we see undergraduate research as an essential component of liberal arts education and not just a specialized vocational program.

A DEVELOPMENTAL STRATEGY

Our strategy for developing research abilities is to immerse freshmen in direct, broad experience with biological systems, to create awareness of research practices in a sophomore seminar for biology majors, to foster component skills in sophomore and junior laboratories, to supervise research projects in the junior or senior year, and to create a venue for oral presentations of research in a required senior seminar. The serial prerequisites of most science curricula follow a developmental model to some extent, so we will limit this discussion to elements of our program intentionally altered from the standard major requirements.

At the end of their first year of college, Kentucky Wesleyan biology majors have typically completed 10 credit hours of a general biology sequence designed specifically for pre-professional scientists and incorporating two 2-hour laboratory periods each week. A similarly structured general chemistry sequence, taken concurrently by most majors, contributes to the total of 240 hours of laboratory time that freshmen receive. Laboratory sessions are taught by the same faculty who teach the lecture/discussion meetings, establishing continuity and flexibility in these courses. Topics in general biology laboratories range from biochemistry to ecosystems, include a diversity of taxa, and vary in approach from controlled experiments to histological observations to field data collection. The theme of the freshman year is direct sensory experience of biological systems. Secondary sources of information, such as computer simulations and videotape presentations are employed later in the curriculum. These technologies are used sparingly at first, though, because representations of this sort convey limited meaning to a student unfamiliar with the natural phenomena they symbolize (Schrock 1985).

Freshman courses outside the natural sciences lend valuable support to our program. Writing workshop is a six credit-hour sequence emphasizing verbal reasoning, composition, and bibliographic research. This English department offering is required of all students, maintains small class sizes, and involves weekly writing practice. The research paper produced in the second semester can be adapted to the student's major interest, and biology students often pursue a scientific problem. A research adviser from outside the English department helps each student with the paper's content; biology faculty frequently serve in this capacity. English faculty have also cooperated with us in presenting unique aspects of scientific writing, such as the embedded citation style and the common use of passive voice in research reports. Kentucky Wesleyan's integrated studies requirement bridges the 'two cultures' of science and humanities (Snow 1959) by teaming faculty from different academic backgrounds for interdisciplinary

courses. Science faculty have collaborated in four of these: 'Health Ethics and Society,' a laboratory-based 'Environmental Science' course, a seminar called 'Catalytic Thinkers in Environmental Science,' and the freshman studies course titled 'Profiles in Leadership.' In support of our objectives, integrated study demonstrates the social environment in which science is conducted and casts the scientist's world view in a clearer light through contrast with other perspectives.

A 1-hour seminar required of all sophomore biology majors brings the second-year cohort together at a time when most have decided on a major but not the details of a career choice. Sophomore Seminar is centered on the research proposal, which lends itself to discussions of many issues relevant to a scientific vocation. Research objectives, bibliographic searching and citation styles, interpreting journal articles, preparing tables and figures, oral presentations, writing strategies, ethical considerations, rules for handling animals and human subjects, statistical methods, experimental design, computer applications, graduate/professional school requirements, and career options are among the topics we discuss. Student participation is evaluated as part of the college's core oral communications requirement. Each component of the student's research proposal is submitted and evaluated in weekly assignments, and the entire proposal is re-written and re-evaluated at the end of the course. The intent of Sophomore Seminar is to give students an overview of the scientific process so that they can see the relevance of the biology curriculum, set their own educational objectives for the next five semesters, and direct their scholastic efforts over the long term.

Upper-division biology courses at Kentucky Wesleyan are fairly typical in their content but exceptional in the depth of laboratory experience provided. The 3-hour time block set aside for the typical laboratory is supplemented by open lab hours for extensive independent work. The location of science faculty offices in or near the student laboratories allows supervision of independent research activity, and students pursue increasingly challenging laboratory problems on their own. The genetics, microbiology, immunology, and embryology courses, in particular, engage students in ongoing research efforts requiring student-generated work schedules, team collaboration, and maintenance of experimental apparatus and records over weeks or months. During this period, students assume greater responsibility for their investigations, and they come to see the laboratory as a facility for creative activity rather than a class to attend for a fixed number of minutes each week. To balance the types of research experience, all majors are also required to participate in a field course, which may be chosen from ecology, field botany, entomology, or marine biology. Support courses in chemistry and physics are similar in their laboratory-intensive, problem-solving approach, and the three departments collaborate extensively to help individual students, tailor schedules, and coordinate curricula.

Because of the growing competence of biology majors and their accumulation of laboratory and field skills, the independent project functions as a capstone activity rather than a novel experience. Students often meet this requirement by conducting the research they proposed in the sophomore seminar. Others participate in off-campus research fellowships or collaborate with faculty on new projects. Each student writes a short proposal for the research before the project begins, and a written report follows the project's completion. The student researcher and faculty adviser sign a research contract to ensure that research objectives and completion dates for project milestones are well defined at the outset. This practice facilitates scheduling and evaluation of the research. Sample topics from student projects over the past few years include biomonitoring of water quality, coelomic infections by acanthocephalan parasites, microbial communities in cooling systems, growth of black band disease in coral reefs, macroinvertebrate population dynamics, genetic bases for sterility in *Drosophila,* flora of a reclaimed landfill, and spatial pattern in whirligig beetle assemblies.

Senior seminar focuses on oral presentation of student research. Seniors in the course are provided guidance in organizing their material, methods for oral presentations, and help in producing 35 mm slides. The course culminates in a half-hour presentation from each student, clocked and followed by questions from seminar participants in the format of sci-

entific meetings. Three biology faculty attend all seminars and provide independent evaluations of each presentation. Feedback from peers is an important part of the process as well. Invitations to the campus community create opportunities to demonstrate our students' accomplishments outside the department, and videotapes of each presentation are kept as a reference library for others.

Co-curricular programs are also instrumental in developing student research efforts. Our pre-professional science society helps students make the transition from college to graduate or professional school. Guest speakers orient students to a variety of scientific careers, as do annual tours of university medical, dental, pharmacy, and graduate schools. Meetings with alumni already placed in graduate programs, always included in these trips, are especially instructive for students with parallel post-graduate aspirations.

ASSESSMENT AND CONCLUSIONS

This educational program was not established as an experiment; it contains too many variables for objective evaluation of the merits of each curricular component. We can, however, provide subjective judgments on aspects of the program that have worked more or less effectively. An obvious cost of this kind of curriculum is the high faculty-to-student ratio required for its success. Although we enjoy extensive contact with undergraduates, the time and energy demanded of faculty are easy to underestimate. Our approach is feasible in the small college context but is probably not a realistic model for larger institutions emphasizing faculty research (Carter et al. 1990). Another drawback to a 4-year curricular strategy is that students forget lessons learned in one semester before being asked to apply them in another. This is especially true of theoretical concepts as opposed to laboratory techniques. The problem must be addressed by frequent cross-referencing and appropriate review. The sophomore seminar, a keystone of the developmental plan, is frequently criticized in student evaluations as too much work for 1 hour of credit. Their appreciation for the sophomore experience tends to grow over time, though, and we get much more positive retrospective remarks from seniors.

Advantages of a 4-year strategy are most apparent when we place more advanced students in contact with beginners. Sophomores are encouraged to attend senior seminar presentations, for example, and the results have been so beneficial that we plan to formalize this arrangement in the future. Juniors and seniors often serve as tutors or laboratory assistants to freshmen and sophomores. This kind of peer mentoring is good for the newer students but also provides valuable review for the more experienced undergraduates. We note that students who have gone through this program generate original research ideas and ask permission surprisingly often to continue research projects after the grading period is over. The practice of keeping textbooks and course materials for future reference has been growing among our students, and we have seen an increase in citations of earlier readings or exercises in the bibliographies of upper-level research reports.

Ultimately, of course, the proof of any undergraduate program is in the performance of its graduates. Our student population is comparatively small, and evidence is necessarily anecdotal, but our alumni consistently acknowledge that this program has contributed to their success. Steve Wilt, a 1992 graduate, was singled out in the 1996 Plenary address to the Kentucky Academy of Science as a key contributor in organizing the neuro-molecular biology program at the University of Louisville (McLaughlin 1996). Presentations by our undergraduates and recent graduates in meetings of the Kentucky Academy of Science (e.g., Melcher and Townsend 1996; Novotny and Rawls 1996), and The Southeastern Society of Parasitologists (Bassett and Oetinger 1996) are consistent with the conclusion that a developmental approach enhances meaningful undergraduate research.

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Undergraduate Research in Kentucky: Biological Sciences

Doing it: The Thing That Makes Science Make Sense

Philip H. Crowley and William S. Cohen

T.H. Morgan School of Biological Sciences, University of Kentucky, Lexington, Kentucky 40506-0225

ABSTRACT

For undergraduate life-science majors, research projects can be more than just another way to earn college credit. Undergraduate research experiences shift the emphasis from the professor as wilderness guide to the student as explorer. Student researchers learn to take responsibility for a project, use available methods and guidance to collect and analyze data, draw appropriate conclusions, communicate effectively with other researchers at all levels of experience, and contribute in their own way to the body of scientific knowledge. Current life-sciences initiatives in undergraduate research at the University of Kentucky (UK) emphasize what we call horizontal and vertical integration of research and training: extending these opportunities to a larger and more diverse group of biology majors and a broader range of life-sciences researchers, encouraging graduate students to serve as primary mentors for undergraduates, and exposing students to the research enterprise very early in their undergraduate careers.

INTRODUCTION

"Textbook science" is an oxymoron. Science is fundamentally an experiential process, a subtle, improvisational game in which nature is cajoled into self-revelation. Though the basic conceptual methods of science are relatively general and accessible, the actual route to obtaining a particular meaningful and convincing result usually depends on a groping procedure that can accurately be called 'systematic blundering.' The tools and techniques keeping this uncertain process on the rails can be fully understood only by finding some of the boundaries beyond which they fail; for example, principles of experimental design become vivid when a major effort is undercut by inadequate controls or insufficient replication. Other people's scientific victories—-or defeats—-just cannot pack the same punch. So reading about science, listening to learned practitioners, and conducting set-piece 'experiments' in an instructional laboratory are not enough, even for beginners. Like the rest of us, beginners need the chance to experience the doing of science and the scope to make constructive errors in a 'real' research project of their own.

In this article, we outline an approach to incorporating undergraduates into an active research environment; we describe some initiatives now underway to implement this in biological sciences at the University of Kentucky. These approaches are still evolving rapidly at our institution and at others in Kentucky and across the country. We welcome the exchange of ideas in this special issue and encourage comments and suggestions on the points made here.

PHILOSOPHY

Unlike the monastic image of brilliant insight achieved in isolation (à la Mendel), contemporary science is highly interactive, and the metaphor of a critical mass of ideas generating an explosion of understanding seems more apt for today. Researchers addressing the same or similar problems within a laboratory, research group, academic unit, university—or (especially in this electronic age) beyond—may interact with sufficient intensity to approach this explosive threshold. This is a process of horizontal integration that can generate and winnow ideas efficiently and mesh complementary contributions. But there are also vertical structure and dynamics in a research environment, corresponding to interactions among individuals at different levels of experience and responsibility. As researcher-educators, we aspire in our own groups to achieve *vertical integration of research and training*, in which individuals at different levels in this hierarchy all contribute to the overall research effort while gaining appropriate knowledge and experience in the process. The result can be an even more stimulating and

productive intellectual environment. But how can we bring this off?

IMPLEMENTATION

This time of rapidly increasing demand for undergraduate instruction in the biological sciences (e.g., see *The Chronicle of Higher Education,* 13 Dec 1996, p. A12) coincides with the advent of powerful molecular and computer-aided methods and of new environmental and health concerns that must be addressed. Getting undergraduates into research laboratories fills in the active and concrete side of their learning cycles (Kolb 1984) and improves our chances of maintaining a scientific talent pool for the future. In the Morgan School at UK, we coordinate an undergraduate research program in the life sciences (URLS) by attempting to match many of the 900 biology majors with the ca. 400 faculty life-scientist researchers on campus. In recent years, about half of our biology graduates have conducted an undergraduate research project by the time they graduate, most of them earning three to six credit hours in the undergraduate research course, BIO 395. We hope to raise this proportion significantly in the near future.

The matchmaking between students and researchers begins with the campus-wide request for a brief program overview and for sketches of possible projects from life scientists, which are then made accessible to students through written materials and postings on the World Wide Web. Students wanting BIO 395 credit for the project must fill out a one-page 'contract,' signed by student and mentor, describing the project and its tentative timetable. Expenses associated with these projects are borne by research-grant funds, REU grants and supplements (the National Science Foundation's Research Experiences for Undergraduates Program), the UK Undergraduate Studies office, the University's Hughes project (see below), or the budgets of academic units. Plans are now being developed, with funds from the Morgan School's Ribble Endowment, to expand the University's Life Sciences Day to include a poster session for all URLS participants and scholarship awards for the best projects.

The UK-Howard Hughes Medical Institute (HHMI) Undergraduate Research Program is a campus-wide effort to promote research and academic careers in the biological sciences, funded by a 5-year, $1M grant. The goal, as for URLS activities in general, is to provide interested and qualified students the opportunity to join a research group and to participate in contemporary biological research under the direction of faculty sponsors drawn from the diverse array of life-sciences specialties at this land-grant university. The Academic Year Research program supports part-time research during a period of two consecutive semesters; students receive academic credit for this through BIO 395 or one of the undergraduate research courses in other academic units. At the end of each semester, students completing their projects present posters describing the approach, results, and implications—the highly successful exercise that we intend to extend to all URLS participants. The Summer Research Program, focused on molecular cell biology, draws students from both inside and outside the University. Summer projects are full time for 2 months, with subsequent presentations by student participants at the fall HHMI poster display and at the annual meeting of the Kentucky Academy of Science.

But these URLS and HHMI research projects provide opportunities mainly for upper-level undergraduates and, though of central importance, cannot by themselves ensure the full range of vertical research integration that we believe to be desirable. For this reason, we have recently launched initiatives aimed above and below this advanced undergraduate cohort to help complete the picture.

Graduate students, particularly those focused on becoming faculty members in the future, need experience in designing and mentoring projects conducted by neophyte researchers. We have therefore proposed a new one-credit graduate course, Mentoring Undergraduate Research Projects in Biology, intended mainly for advanced graduate students who have already completed the doctoral qualifying examination. The course instructor, ordinarily the graduate student's research supervisor, is the faculty member most appropriate for overseeing the undergraduate project and for guiding students along the way. This potentially opens new project opportunities for undergraduate students, documents

the graduate student's contribution in the transcript, and inevitably deepens the graduate student's understanding of the research itself and of what constitutes a viable project. This kind of mentoring opportunity could in some cases be extended to talented master's students or even to experienced undergraduates, perhaps with more extensive faculty oversight.

At the other end of the experience spectrum—incoming freshmen—we have a student group with little concept of research activities and opportunities at a research university whose mission is strongly linked to the life sciences. Often, the situation is most acute for members of groups under-represented in science. To address this, we have begun a freshman orientation course in the life sciences, BIO 101, in which researchers and advisers from some of the University's many life-sciences programs describe research opportunities and career possibilities within their fields. This year, in collaboration with the University's Office of Minority Affairs, we are piloting a biointern program designed to give some incoming biology students a work space within a research laboratory and early exposure to the active research enterprise. We hope that the relationships and experiences developing from this arrangement will improve retention of these students, encourage their interest in science, and attract them into conducting research projects of their own.

CONCLUSION

Understanding science as an active process depends on committing and recognizing those constructive errors that move a research project forward. Moreover, undergraduates conducting such projects can be significant contributors to the research enterprise, particularly when slotted appropriately into an interactive continuum of research expertise. But the best way to facilitate these outcomes is to continue the educational meta-experiment: perhaps the ongoing undergraduate research initiatives across the country will begin to converge on approaches that most effectively expand opportunities for students, while making them real participants in the advancement of science.

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research in Biology at Centre College

Christine K. Barton and Anne E. Lubbers

Division of Science and Mathematics, Centre College, Danville, Kentucky 40422

ABSTRACT

Centre College is an undergraduate liberal arts institution that promotes active research in which the main objective is education of the student rather than publication of papers. Small class size and the absence of a graduate program enhance our ability to provide the type of high quality research experience that makes our students well-qualified candidates for graduate school. The level of undergraduate research in the Biology (BIO) and the Biochemistry and Molecular Biology (BMB) programs has grown since 1988, primarily due to greater availability of funding. Since 1991, ca. 30% of BIO and BMB majors have undertaken a formal research project, either on campus or at another school. Nearly half of these students continued their education in a biology- or health-related field. Success of an undergraduate research program requires adequate compensation for both students and faculty in the form of stipends, funding for supplies and equipment, and awarding of academic or teaching credit for time spent. As availability of funds declines and demand for undergraduate research opportunities increases, one creative solution to the conflict may be the development of collaborative programs between graduate and undergraduate institutions.

INTRODUCTION

In accordance with our liberal arts philosophy of training 'the whole person,' we at Centre College view undergraduate research as complementary to our primary task of teaching. Not only does faculty research help us bring current scientific concepts and excitement to our classrooms; when done collaboratively with students it provides them with the tools and self-confidence to find answers to questions on their own. Recognizing that previous research experience is one of the criteria used by graduate institutions in selecting new graduate students, we are committed to providing such experience to our students to improve their chances of postgraduate success.

Indeed, our programs uniquely suit us to providing high-quality undergraduate research experiences. One of the advantages of doing research in the smaller-college environment is that undergraduates are not competing with graduate students for money, equipment, and attention. Moreover, because our class sizes are restricted to fewer than 30 students, and we often have the same students in more than one course, we get to know our students well and can easily identify and encourage those who would most profit from doing research with us. In turn, students feel comfortable enough to approach us about doing research, often based on a continuation of a project begun in class. An added advantage is that we have detailed knowledge of what the student has experienced in the classroom so we can better build on that knowledge during the research project itself.

Another major difference between undergraduate research programs at small colleges and those done where graduate programs exist is that the student, rather than publishable research itself, is our final product. Students can play an active role from design to presentation of their research. Even where the faculty member determines the subject and goals of the study, the project is more likely to be self-contained rather than a less well-defined component of a large study.

Undergraduate research programs do involve a variety of costs. The cost most commonly addressed is that of funding for equipment, supplies, and stipends. If and when such funding is provided, however, other costs come to the forefront. For instance, the increased expectation by students for research opportunities may outstrip the availability of major facilities (laboratory space, dormitory rooms) and faculty time. As student research becomes more successful, there is danger that the administration will increase the pressure on faculty to maintain their level of commit-

ment, so that faculty feel obliged to spend more of their summers in a continuation of their teaching role. At the same time, the administration may expect that publication and grant proposal-writing should increase. It should not be forgotten that the time faculty spend in student research is more akin to teaching than research; the amount of publishable research accomplished is often reduced, and when done in the summer it cuts short the 'rejuvenation' period between academic years. These costs suggest that optimal rather than maximal research levels must be defined and pursued.

HISTORY

Prior to 1988, undergraduate research in biology was encouraged at Centre College but the lack of readily available funding often limited the scope of these efforts, particularly in summer. From 1988 to 1991, two of the biology faculty at Centre (M. Barton and C. Barton), in collaboration with selected faculty from the University of Kentucky (P. Crowley, A. Sih, C. Sargent), served as Co-PI's for an NSF REU Grant. During each of the four summers from 1988 to 1991, two or three Centre College students participated in summer research projects at the UK Aquatic Research Facility under the mentorship of faculty from Centre and the University of Kentucky. Since summer 1992 Centre College undergraduate research projects have been funded through a 5-year grant to the college from the Howard Hughes Medical Institute. Individual faculty members have also obtained external grants that have funded some collaborative research projects. In addition, Centre College has a long-standing tradition of internally supporting individual faculty requests for collaborative research projects through the Faculty Development Committee.

THE PRESENT STATUS

Currently, Centre College offers two different majors in the biological sciences: Biology(BIO) and Biochemistry/Molecular Biology (BMB). There are seven full-time and one part-time faculty members teaching in the BIO and BMB programs. Each year, about 30 students (15% of the senior class) graduate with either a BIO or a BMB major (Table 1). Although our majors are not required to do an

Table 1. The number of graduating students majoring in the biological sciences over the past 6 years and the total number (and percentage) of students pursuing undergraduate research projects during either the summer months or during the academic year at Centre College. "For credit" indicates those students who received academic credit for their summer research; "No credit" indicates those students who did not receive academic credit for their research.

		Number of students pursuing research projects			
			Summer only		
Year	Number of graduates	Total	For credit	No credit	School year
91–92	26	10	4 (40)	0 (0)	6 (60)
92–93	22	12	2 (16)	1 (8)	9 (75)
93–94	34	8	3 (38)	2 (25)	3 (38)
94–95	41	7	1 (14)	2 (29)	4 (57)
95–96	45	13	6 (46)	0 (0)	7 (54)
96–97	31	9	5 (56)	0 (0)	4 (44)
Totals	179	59	21 (36)	5 (8)	33 (56)

independent research project, we have a strong record of student participation in undergraduate research. Overall, it would be fair to state that currently all BIO and BMB majors who seriously want to undertake an undergraduate research project are able to pursue such an opportunity at some time during their 4 years at Centre.

Since the 1991–1992 academic year, over 30% of all Centre students majoring in either biology or biochemistry/molecular biology have elected to undertake a formal research project (Table 1). The majority of these students pursued research during the school year (Table 1). This level of student participation in undergraduate research has been facilitated by the availability of both internal and external funding provided through sources such as NSF, EPSCoR, the Howard Hughes Medical Institute, USDA, Lilly Foundation, and the Teagle Foundation (Table 2). This funding has been especially pivotal in the establishment of a strong summer research program at Centre.

The Hughes grant is a particularly noteworthy example of the very positive impact that funding can have on the establishment of a strong undergraduate research program at a small college. With the Hughes funding, we have been able to support annually four or five students working on biological research projects and another six or seven students pursuing other areas of scientific research during

Table 2. The sources of both internal and external funding used to support undergraduate research projects at Centre college from 1991 to 1996.

Source of funding	Total number of students supported
External funds	
NSF–REU grant (Summer 1991)	3
Hughes Medical Institute (1992–1996)	19
Other external sources (NSF, USDA, EPSCoR)	4
Internal Funds	
J. C. Young Scholars Program	6
Unfunded	27
Total	59

each of the past five summers. Students selected to conduct these summer research projects receive a stipend and a housing allowance; in addition, they can elect to continue the summer project during the fall term by registering for independent study credit. Generally, if the preliminary results of the research project seem promising, the student is encouraged to complete the data analysis and to prepare the results for presentation at the fall meeting of the Kentucky Academy of Science.

During the school year, students can elect to pursue undergraduate research projects under three different programs. The John Young Scholars program allows the strongest students to pursue a year-long project during their senior year. This college-wide, competitive honors program is open to qualified seniors interested in undertaking an extensive research project in their major field of study. Students competing annually for the six to eight Young scholars positions submit and defend their research proposals at the end of their junior year. If they are selected as Young scholars, they spend two of their final three terms completing the research project and presenting the results as part of a campus-wide symposium in May of their senior year. In addition, the formal papers written by the Young scholars are published annually by the college. Although the Young scholars program does not provide a stipend for student researchers, there is a modest supplies budget that is awarded with this honor. Students who do not qualify as Young scholars may elect to pursue a non-honors research project during any academic term, particularly in the junior or senior year. Generally, these students will receive academic credit for their independent research project. Finally, Centre College has an active internship program providing selected off-campus research opportunities for our BIO and BMB majors. During the 6-week-long winter term, students have pursued ongoing research projects in areas such as molecular genetics, plant pathology, and cancer research at institutions such as the University of Arizona, University of Arkansas, Vanderbilt University, University of Kentucky, or Washington University. Currently, the internship program emphasizes molecular areas of study; in the future, we would like to establish new internship opportunities focusing on organismic areas of research.

In addition to the on-campus research opportunities available to biology majors at Centre College, several of our majors participate in a number of summer research programs conducted at other institutions. In the past several years, we have had Centre students engaged in summer research projects at the University of Kentucky, University of Louisville, Miami University (Ohio), Vanderbilt University, University of Georgia, Rocky Mountain Biological Laboratory, and Cranberry Lake Biological Station, among others.

IMPACT OF UNDERGRADUATE RESEARCH EXPERIENCES ON STUDENTS

Of the Centre students choosing to pursue undergraduate research projects in the biological disciplines, nearly half continue their biology education in some type of postgraduate programs relating to biology (Table 3). Of the 25 students who continued their education, 13 enrolled in graduate programs in the biological sciences. Female graduates are more likely

Table 3. Post–graduate pursuits for students receiving academic credit for undergraduate research at Centre College over the past 6 years.

Post–graduate pursuit	Number of students	
	Males	Females
Medical school	5	2
Graduate school in biological sciences	5	8
Other professional school relevant to biological sciences[1]	3	2
Lab tech/researcher	1	6
Hospital technician	1	0
Pharmaceutical sales	1	0
High school biology teacher	0	1
State/Federal Biologist	1	0
Unknown or non–biological pursuits	7	9
Totals	24	28

[1] Dental, veterinary, and pharmacy schools.

to continue these studies in a graduate school program, whereas male graduates tend to continue their education in medical school. A significant proportion of our undergraduate researchers did not immediately continue their education following graduation from Centre College. This trend is reflected in the large number of students in the unknown/other category. Included among these 15 students are six students who have pursued research projects during the current academic year but have not yet focused their future career plans.

During the past 6 years, seven students have received academic credit for participating in two undergraduate research projects. These students account for the discrepancy between the total number of students in the three tables. The opportunity to participate in more than one research project is readily available to motivated students at small undergraduate institutions, allowing these students to narrow their broad interests in biology before applying to graduate schools.

FACTORS INFLUENCING FACULTY AND STUDENT RESEARCH PARTICIPATION

Clearly, the availability of external and internal funding largely defines the potential level of undergraduate research at Centre. Once funding is available, however, other factors will determine whether or not students decide to take advantage of the opportunity to do research. For instance, we advertise research opportunities during advising sessions and through announcements, and we specifically identify and encourage particularly promising students to join us. There also are the added incentives of receiving academic credit for research done during the academic year and stipends for that done during the summer. A more subtle influence is the atmosphere created, which may entice students to get involved. We bring in seminar speakers and create enthusiasm by hosting an annual poster session in which students can display the results of their work to the college community. The occasion of the annual KAS meeting requires practice sessions and travel as a group to the meeting itself. As a result, we have seen a growing sense of camaraderie and pride among our young researchers and a greater acceptance of the importance of including this experience during their 4 years at Centre.

It also is essential to make undergraduate research attractive to the faculty. In general, faculty at undergraduate institutions welcome the opportunity to do research; in fact, tenure and promotion are usually tied to some level of research. Research, however, necessarily draws time and attention away from our primary teaching mission. At Centre, student research projects are possible primarily through the dedication of faculty to the students, with only occasional faculty compensation for these research efforts. During the summer months, we may receive a nominal stipend in conjunction with our collaborative research participation. Both the Hughes grant and the EPSCoR program have allowed Centre faculty to receive some release time in conjunction with collaborative research efforts during the past 5 years.

An additional factor that influences faculty participation in undergraduate research at small colleges is isolation from their colleagues at the large institutions. Commonly, each faculty member at a small college is *the* expert in a particular area of biology. The establishment of new collaborative research efforts between faculty at small colleges and those at research institutions may be desirable in order to broaden the types of undergraduate research projects undertaken at both institutions.

THE FUTURE

During the past 5 years, Centre's strong commitment to undergraduate research in biological disciplines has been possible due to a number of factors: availability of funding, dedication of the faculty, and qualified students. In the future, we anticipate an on-going demand for a strong, visible undergraduate research program in the biological sciences. To ensure the maintenance of a wide range of high-quality research experiences, we expect that we will be faced with a number of challenges in the years to come. Funding clearly will be a significant challenge. The college-wide demand for the available inhouse funds far exceeds the supply and there is increased competition for the limited funds available each year. Moreover, our major external source of funding for summer undergraduate research in the biological sciences over the last 5 years, the Hughes grant, will run out this year. Since the summer projects supported by these funds are most likely to generate the types of results that will allow students to present their research at scientific meetings, the overall visibility of undergraduate research may decline if funding for summer programs is not continued. Currently, we are faced with the challenge of obtaining additional sources of funding for the on-going support of the undergraduate research program that has become established at Centre College over the past decade.

In addition to funding, adequate compensation for faculty is essential for the continued maintenance of strong undergraduate research programs. As the demand for undergraduate research escalates, undergraduate institutions, where the teaching load is traditionally very heavy, will need to develop curricular mechanisms for systematically compensating faculty for their collaborative research efforts. Ironically, with the end of the funding and faculty release time provided through the Hughes grant, BIO and BMB faculty at Centre College are facing greater student demand for research opportunities.

The attractiveness of undergraduate research opportunities to qualified students depends on a wide variety of factors. Compensation in terms of stipends and academic credit is essential. The continued availability of funding is critical for the continuation of summer research programs since most students cannot afford to participate in research unless they are paid a stipend. At Centre, the 3 hours of academic credit that most students earn in conjunction with research projects can be applied toward the requirements of the major. In addition, there is in-house money available for sending students to meetings if they obtain results worthy of either a paper or a poster presentation. Undergraduate students also need reassurance that funded research opportunities will continue to exist at the graduate school level in all biological disciplines.

The importance of undergraduate research opportunities needs to be continually emphasized to the administrations of primarily undergraduate institutions. At Centre, we are fortunate enough to receive administrative support for the John Young Honors Program that has successfully allowed several of our strongest students to pursue research during the academic year. Over the years, this program, which is funded through in-house monies, has experienced a number of significant budget cuts, reducing the number of students who can be funded and also reducing the total amount of funding available for research supplies, etc. Graduate and professional schools need to continually remind undergraduate institutions of the need for continuing in-house support for these research opportunities.

In the future, faculty at small colleges and larger research institutions will need to collaboratively address the increasing demands for undergraduate research programs. We would challenge the larger research institutions to consider providing additional opportunities for professional activities that would strengthen the ties between the undergrad-

uate and graduate institutions in this region. For example, regional symposia focusing on particular areas of research would permit exchange of ideas and presentation of results based on collaborative studies. Advertised speaker's bureaus would provide a readily available list of faculty willing to visit the small colleges to share the results of their research and also to witness the types of research being done by our undergraduates. Collaborative funding of undergraduate research programs may provide one creative solution to the impending funding crisis facing all scientific research efforts. The NSF-funded REU program, a collaborative effort between the University of Kentucky and Centre College, could serve as a model for this type of cooperative research experience. Successful funding for undergraduate research programs will be essential as we in the biological sciences continue to train our future graduate students.

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research in the Biological Sciences at Kentucky State University

Karan Kaul

Division of Mathematics and Sciences and Community Research Service, Kentucky State University, Frankfort, Kentucky 40601

and

Paul A. Weston

Community Research Service, Kentucky State University, Frankfort, Kentucky 40601

ABSTRACT

The bulk of undergraduate research in the biological sciences at Kentucky State University is done by students enrolled in Special Problems in Biology, a two-credit-hour course required for all biology majors. Most students conduct laboratory research projects with research scientists in KSU's Land Grant Program or with a biology faculty member. The undergraduate research program has proven to be rewarding for students as well as for their mentors and has resulted in numerous presentations at scientific conferences and several publications in refereed journals.

INTRODUCTION

Kentucky State University (KSU), the smallest of the eight public universities in Kentucky, has a student enrollment of about 2500. The biology curriculum is administered through the Division of Mathematics and Sciences; currently there are about 120 students majoring in biology. During the 1988–1989 academic year, after a review of the biology curriculum, a committee consisting of three biology faculty members recommended that Special Problems in Biology (BIO 410) be a required, one-semester, two-credit-hour course for students seeking a B.S. in biology from KSU. Before this time, this course was offered as an elective. The recommendation was supported by the biology faculty as a whole; after due process BIO 410 was listed as a required course for biology majors in the 1990–1992 KSU catalog. The biology faculty felt that undergraduate research would provide students with practical experience in how scientific knowledge is accumulated by formulation of hypotheses, experimental testing of these hypotheses, collection of experimental data, and interpretation of data to draw logical conclusions. It was our hope that the experience would encourage some students to consider graduate school as an option after graduating from KSU.

During the 23 semesters from fall 1989 to spring 1997, a total of 163 students took BIO 410 (an average of about seven students per semester). The other avenue available to biology majors for getting involved in research at KSU is to get part-time employment in research projects that are part of either the Land Grant Program (LGP), which is sponsored by the U.S. Department of Agriculture, or the Minority Biomedical Research Support Program (MBRS), which is sponsored by the National Institutes of Health. The LGP supports agricultural research and extension projects designed to remedy problems faced by farmers, especially limited-resource farmers, in Kentucky. The program encourages involving undergraduate students in research and extension projects. The main emphasis of the MBRS program is facilitating involvement of students in biomedical research at predominantly minority institutions, such as KSU, and helping them learn about careers in the biomedical research area.

All biology majors take BIO 410 once during their junior or senior year; some take it a second time as a biology elective course. Students in the course have the option of doing

a library or laboratory research project. In the first option students write a detailed paper based on their library research on a particular topic; in the second option they complete a laboratory research project and write a report in a journal format. Almost all students choose the second option. A biology faculty member is in charge of the course each semester. This faculty member supervises and evaluates all library research projects. Laboratory research projects are supervised and evaluated by the individual in whose laboratory the student does the work. These supervisors include members of biology faculty or, more often, one of the research scientists working in the Land Grant Program at KSU. Rarely, students choose an off-campus venue for their project. Students often present an expanded version of their project in a seminar as part of a required, one-credit hour Biology Seminar. Students are also encouraged to present their research findings at scientific meetings. On an average, five to 10 poster and oral presentations per year are made by KSU biology majors at annual meetings of Kentucky Academy of Science; at Minorities in Agriculture, Natural Resources, and Related Sciences; at National Minority Research Symposium; and at other scientific conferences. Students are also co-authors of many other presentations. During the period 1992 to 1996, undergraduates co-authored eight research publications in refereed scientific journals.

RESEARCH PROJECTS AT KSU

Ongoing research projects at KSU provide students with an opportunity to gain experience in a variety of research areas such as plant physiology, sustainable agriculture, behavioral entomology, stored grain entomology, horticulture, apiculture, water quality/environmental science, animal and human nutrition, aquaculture, and toxicology.

In our experience, a research project in any area can be suitable for undergraduate research as long as (1) it is part of ongoing research so the supervisor has an added incentive to spend time with the student and (2) it is well defined so that the student clearly understands the scope of her/his project and gets the satisfaction of having completed the project at the end of the semester. Care must be taken to choose only such projects for undergraduate research that will be very likely to yield meaningful data within a relatively short period of time (10 to 12 weeks). A well-planned, detailed follow-up on a promising preliminary experiment will have an excellent possibility of becoming a successful undergraduate research project.

One of the most suitable groups of organisms for undergraduate projects in zoological research is stored-product insects, particularly beetles. These insects require very little space, no specialized equipment, and minimal maintenance. The life cycle of these insects is typically 4–5 weeks, and there exists a large body of literature concerning various aspects of the biology of these organisms, particularly the red and confused flour beetles (*Tribolium castaneum* and *T. confusum,* respectively). Rearing materials are inexpensive and easily obtained (e.g., mason jars, flour, corn meal, oats, and other common grocery items). One piece of equipment that one might wish to purchase is a brass sieve (cost ca. $50) for separating insects from the dietary medium, but one can easily substitute a kitchen or homemade sieve for this purpose. Although a controlled temperature environment might be required for rearing studies, room conditions are perfectly adequate for many other types of studies provided that temperature fluctuations are not great.

The short life cycle of these insects means that, with careful planning, experiments spanning two or three generations can be conducted within the time limits of a semester. Because of their modest living requirements and the fact that stored-product insects naturally inhabit environments not significantly different from conditions existing in a mason jar in a laboratory, ecological studies with a fair degree of relevance to natural systems can readily be conducted in the laboratory. Projects dealing with physiology, behavior, and community ecology are a few types of studies that can be readily conducted. A number of influential studies on animal population dynamics have been conducted with *Tribolium* spp. (Dawson 1968; Park 1948, 1962; Sokoloff and Lerner 1967; Watt 1955).

An additional advantage of working with insects as test organisms is that insects have generated little concern regarding animal rights. This does not mean that one is free to abuse

insects, but it does mean that no special permits are required to conduct research projects using insects as test animals. In addition, insects can be humanely euthanized by freezing them, and no special handling is required for disposal of their carcasses (dead insects are not considered biohazardous waste).

BENEFITS TO STUDENTS

Opportunities for conducting research at the undergraduate level provide an extremely important dimension to the overall scientific education process. The benefits to students are so numerous it is difficult to justify *not* offering such opportunities to undergraduates. The contributions to the education process exist at a variety of levels, as enumerated below.

Living the Scientific Method

The most obvious benefit of engaging undergraduates in research projects is to allow them to experience the scientific method in ways that coursework, even in laboratory courses, cannot provide. Perhaps the most satisfying research experience is one allowing investigation of a phenomenon that has yet to be studied. Guidance from the research adviser is usually required to direct students in the development of hypotheses and experimental design, but the thrill of discovery that novel research provides is an incomparable experience for students.

Appreciation of the History of Science

Having to go through the process of generating, testing, and revising hypotheses also provides students with a unique perspective on the history of scientific thought. Even though the evolution of various scientific concepts is often taught in the classroom, the experience of testing hypotheses where the outcome is unknown in advance increases one's appreciation of the processes involved in the scientific explorations that led to the development of such important concepts as the cell, gene, evolution, etc. The experience no doubt helps students to evaluate scientific papers more critically.

Professional Development

The contribution of the research experience to professional development is probably the most tangible outcome. For students planning to pursue a career (or at least graduate studies) in science, the benefits of engaging in research at an early point in their education are incomparable; gaining an understanding of how to conduct experiments, analyze data, and prepare scientific presentations and manuscripts are just a few. And of course, being able to put a scientific paper on one's curriculum vitae during the undergraduate years is a great confidence-and-credential builder.

Application of Multidisciplinary Skills

Aside from the strictly scientific educational benefits provided by involvement with a research project, exposure to a number of other skills and discipline areas is extended to students. The research project demands that students exercise logic in developing hypotheses, designing experiments, and interpreting results. Although great depth is not possible with a project conducted within the confines of one semester, fundamental statistical concepts and rudimentary analyses can be introduced naturally in the course of the project. Finally, computer skills and experience with various types of software applications (word processing, spread sheets, data analysis, and graphics) can be introduced to students in the logical course of their project. The early experience with all of these multidisciplinary skills can constitute a real advantage later in their academic careers because it allows students to focus on more advanced topics.

Overall, the involvement of undergraduates in research projects at Kentucky State University has been a win-win proposition. Researchers have had additional hands and minds to conduct research projects that might never have had high enough priority to receive their attention; more importantly, students have had their educational experiences richly enhanced by conducting research in the laboratory of career scientists. Although recruitment of students into scientific careers is one desirable outcome of this learning experience, merely increasing the student's appreciation of the scientific method by hands-on involvement in research is enough to justify the continuation of the symbiotic relationship created by opportunities for undergraduate research such as those through Special Problems in Biology.

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research in Biology (1987–1997) At Berea College

Ronald B. Rosen and Ralph L. Thompson

Department of Biology, Berea College, Berea, Kentucky 40404

ABSTRACT

A synopsis of undergraduate research in the Department Of Biology at Berea College in 1987–1997 is presented. Forty-five students and nine faculty members have been involved in 40 research projects. Through research participation, these students have improved their communication skills, applied the scientific method, and enhanced their success in graduate and professional schools; faculty members have increased professional growth activities. Berea College has promoted and supported scholarly research opportunities over the last decade utilizing several new grant sources and the College Labor Program. Currently, results from undergraduate research have been incorporated into 20 presentations, 9 published abstracts, and 7 refereed articles, each having multiple student authors.

INTRODUCTION

This paper summarizes the last decade (1987–1997) of undergraduate research in the Department of Biology at Berea College. The current biology faculty is composed of seven members. Five full-time personnel are an animal behaviorist, botanist, developmental biologist, microbiologist-geneticist, and parasitologist. An adjunct member is an agronomist in the Department of Agriculture and Natural Resources, and a part-time faculty biologist teaches primarily anatomy and physiology and introductory biology. Fourteen to 20 students have graduated from the department each year during the last decade.

Limited research was conducted in the department between 1962 and 1987. A few students were involved in research projects under the direction of two faculty members in cooperation between Berea College and the USDA Forest Service Northeastern Experiment Station in Berea from 1982 to 1987. Unfortunately, the USDA research lab closed down in 1991, ending opportunities and financial support for undergraduate and faculty research at that facility. New grant sources and departmental personnel over the last 10 years have significantly increased opportunities for undergraduate research in biology at Berea.

The majority of these research projects have been conducted in summer, but several have continued as independent studies or labor assignments into the regular academic year. Where continuation into the regular academic year has not been possible, several summers have usually been required for project completion. Marked faculty–student interaction, a characteristic of all of these studies, ranges from an initial, intensive training period to daily interaction. Students have continued ongoing projects and, in a number of cases, have assisted in designing new studies. Following completion of projects, students have usually been required to analyze their data and prepare it for presentation at department and professional meetings.

UNDERGRADUATE PROJECTS, PRESENTATIONS, AND POSTGRADUATE STATUS

Undergraduate research in biology at Berea has involved 45 students (11 of whom participated in multiple projects) and nine different faculty members over the last decade (Table 1). Research results have been incorporated into 18 oral presentations and two poster sessions at state, regional, and national meetings (Kentucky Academy of Science, Association of Southeastern Biologists, Northwest Scientific Association, and National Council for Undergraduate Research). Nine research abstracts have been published in the *Transactions of the Kentucky Academy of Science, Bulletin of the Association of Southeastern Biologists,* and *Northwest Scientific Association.* Seven student articles with or without faculty co-authors have been published in the *Transactions of the Kentucky Academy of Science, American Society of Surface Mining and Reclamation Pro-*

Table 1. Undergraduate biology research conducted by the Department of Biology at Berea College during 1987–1997. Multiple authors are always involved.

Discipline	Projects	Students	Presentations	Abstracts	Articles
Botany	14	12	9	8	2
Cell and molecular	2	2	2	–	–
Developmental	2	7	1	–	–
Environmental	6	7	–	–	1
Entomology	1	1	–	–	–
Herpetology	4	7	1	–	–
Microbiology	5	9	–	–	–
Ornithology	2	1	1	1	1
Parasitology	4	10	6	–	3
Total	40	56	20	9	7

ceedings, Communications in Soil Science and Plant Analysis, The Kentucky Warbler, Castanea, and *Parasitology.*

Over 95% of these undergraduate participants have graduated or will graduate from Berea College. Most of these students have attended or will attend graduate school and other professional schools. During the last decade, students from this group pursued advanced degrees in biology, agriculture, or the professional and allied health fields at Auburn University, Eastern Kentucky University, Indiana University, Johns Hopkins University, University of Florida, University of Kentucky, University of Kansas, University of Minnesota, University of Notre Dame, University of Rochester, University of Tennessee, University of Toledo, Washington State University, and Washington University at St. Louis.

Graduate fellowships, teaching assistantships, and/or research assistantships have been awarded to all of these graduates who have entered advanced degree programs. Special scholarships have been available to those entering allied health fields, e.g., medical schools, physician assistant programs, physical therapy, medical technology, and advanced nursing programs. Special awards on the college and national level have also been based in part on undergraduate research activities. Two of the last three Thomas J. Watson Fellowships awarded at Berea College for travel and study abroad have been to biology majors; one of these individuals also received a National Phi Kappa Phi Fellowship. Each of these students had made presentations and has published abstracts and at least one article as a result of their undergraduate research experience in the Department of Biology. Berea College honors awarded to biology majors involved in faculty/student research include the Stanton King Research Award, Austin Scholar, Wood Scholar, Bangson Biology Award, Brann Biology Award, and Crawford Conservation Prize.

FUNDING

The Department of Biology has benefitted from several recent research grants. In 1986, the Jessie Ball duPont Religious, Charitable, and Educational Fund provided Berea College with a $150,000 grant for 3 years of undergraduate research in the sciences. In 1990, the W.M. Keck Foundation awarded the college a grant of $85,000 to support 3 years of faculty/student research in the sciences. About 43% of the duPont funds and 30% of the Keck grant were ultimately committed to biology research. The department was also the recipient of a Merck Company Foundation Undergraduate Science Program Grant in 1987 that provided $22,500 over 3 years; this grant was subsequently renewed for $39,000 over 3 additional years. In all three cases, science/biology faculty were required to submit research proposals for an "in-house" review by the academic dean and a grant review committee composed of science faculty.

An individual grant from Research Corporation (Cottrell College Grant) was awarded to a faculty member in 1988 for $16,000 over two summers. Beginning in 1995, the Appalachian College Association (ACA) began to administer individual grants from the Andrew Mellon Foundation Trust for successful undergraduate research proposals to liberal arts faculty at 33 participating Appalachian colleges from five states. To date, $22,230 has been awarded to

Berea biology faculty from this source. The college has matched these grants with funds from the Berea College Labor Program to cover student stipends.

Berea College has recently set aside ca. \$18,000 annually for undergraduate research in all disciplines. These Faculty–Undergraduate Research Grants are contingent on faculty initially seeking support from external sources. Proposals are evaluated by the college's Professional Growth Committee. The biology adjunct has received \$6400 from this source over the last 2 years. During this decade, it should be noted that the Berea College Labor Program has routinely provided funds for undergraduate research assistants in the summer and the regular academic year.

In 1992, The Kresge Foundation approved a \$150,000 Science Initiative Grant toward the purchase of new scientific equipment at Berea College to be used in teaching and research. This money was awarded on a challenge basis and required the college to raise an additional \$600,000, creating a permanent endowment for the purchase and maintenance of such equipment. Coupled with this initiative, the Department of Environmental Science and Technology hired an expert in science instrumentation in 1995 to assist the College in maintaining equipment across campus. Thus, science faculty now experience very little "down time" in their research because of equipment failure.

BENEFITS OF UNDERGRADUATE RESEARCH

The Department of Biology (i.e., faculty and students) and Berea College all benefit from a viable undergraduate research program. Students are provided with an opportunity to increase their knowledge and appreciation of experimental design, techniques, and trends through actual participation in research activities. They learn by observing, recording, analyzing, and interpreting scientific research data. Communication skills are increased through reading primary literature, oral presentations, poster sessions, and preparation of manuscripts. Undergraduate research enhances application and acceptance to graduate and professional schools and also increases student competitiveness in the job market.

One of the most common recommendations that recent graduates provided in our 10-year departmental self-study was to increase opportunities for undergraduate research. Given the limitations on personnel and time within our department, an expansion of our research program would likely be best handled by a research methods course or by increasing opportunities for research projects in courses in our current curriculum. Either of these strategies, coupled with both our current on-campus projects and off-campus research opportunities (e.g., research internships and field studies at other institutions, companies, etc.), should provide the majority of our majors with a research experience prior to their graduation. Although not a focus of this paper, off-campus experiences have also been valuable to our undergraduates, and about half of our biology majors have participated in these activities at some point in their undergraduate experience.

Undergraduate research is also an essential part of the teaching and continued professional growth of faculty. The 'professional isolation' and stagnation that faculty frequently experience at small schools is often countered by research programs that provide stimulation and support for further professional development. Interaction with colleagues maintaining similar research interests is increased and may even result in new off-campus opportunities for undergraduates. In addition to the constructive process of generating new research proposals and submitting manuscripts for publication, innovative laboratories, lecture topics, and field exercises have been developed and have become important elements in our curriculum.

Finally, the biology undergraduate research program contributes to the overall reputation of Berea College as an institution where scholarly research is both supported and valued. Donors are attracted to institutions with active undergraduate research programs. Presentations, abstracts, and articles are by-lined from the Department of Biology of Berea College.

SUMMARY

Active undergraduate research programs in the Science Division have long been the standard at Berea, and there are indications that such programs are rapidly spreading to other

departments because of the obvious benefits. Recognition of these benefits in Berea's new strategic plan has led to the recommendation that the College establish an Undergraduate Research and Creative Projects Program (URCPP) that would support faculty/student research and creative project activity across all disciplines. The excitement and knowledge acquired through these opportunities is best summarized by a former student: "There always existed a new task or question to explore . . . several real-world attributes were required while working in such a research environment including discipline, patience, oral and written communication [skills], teamwork, leadership, repetition, and creativity."

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research at Asbury College

John A. Brushaber and Richard B. Reznik

Asbury College, Wilmore, Kentucky 40490

ABSTRACT

The science faculty at Asbury College recognized several years ago the importance of undergraduate research as a component of our academic program. We found that research experience was becoming a more common criterion for admission of our students to graduate school. At that time our students were carrying out laboratory exercises in most of their science classes but were not doing intensive, integrated investigations of biological or chemical phenomena. Only the occasional student was doing research as an independent study.

We decided that actually doing research is important in the education of science majors, whether their career goals are teaching, research, or the health professions. With this in mind, beginning with the 1992–1993 school year, we began requiring senior research of all science majors, except those in pre-nursing or medical technology tracks. To facilitate the research program three new required courses were added to our biology and chemistry major requirements:

BIO/CHE 392 (1) Introduction to Research. A practical experience introducing students to the methods of scientific research and writing. The topic for an independent research project is chosen, and a literature search is initiated.

BIO/CHE 400 (2) Senior Research. Students will under faculty supervision, independently design and carry to completion an independent research project of a biological or chemical nature.

BIO/CHE 475 (1) Senior Seminar. Designed to provide practical experience in the oral presentation of a scientific paper. Students will prepare and present a seminar on their research projects.

ADMINISTRATIVE SUPPORT

The administration has supported undergraduate research by granting each faculty member a 2-hour course load credit each fall semester for supervising students doing senior research. We are also appreciative of the college's willingness to help finance purchase of major pieces of equipment needed for in-house research.

LOCATION OF RESEARCH

Most of our students meet their research requirement in one of three ways. About half of them do their research at the University of Kentucky (UK) in conjunction with laboratories and professors there. About a quarter of them conduct some sort of project using Asbury College's facilities. The remainder fulfill their research requirement doing summer research at a university, spending a semester in a tropical biology program, or participating in a research project at various government agencies. For example, we had two students who spent a semester doing research with the U.S. Department of Energy. We encourage our more capable students to apply for summer fellowship programs in undergraduate research that are funded by the National Science Foundation (NSF). These programs have the advantage of giving the students a long-term research experience with other gifted students in a challenging setting. Typically the students conduct research that is on a graduate school level. Several students have been awarded NSF fellowships, and they have all done well.

There is a trade off of benefits between doing research on our campus and doing it at UK. At UK our students typically do relatively sophisticated research in an established laboratory with an ongoing project directed by a scientist doing significant research. The downside of being assigned a piece of an established research project is that it sometimes requires little creativity or independence on the part of the student. Left to their own devices, students typically have a hard time envisioning

and choosing an avenue for investigation. Our own facilities limit the types of research students can do at Asbury. Research done at our campus, although perhaps more creative on the part of the student, is often less sophisticated, at least in the biological sciences. However, our chemistry department has an ongoing project on transition metal catalysis of peptide synthesis. Another advantage of work at UK is the regular scheduling of lab hours. Students doing their research at Asbury without a fixed schedule are more inclined to procrastinate.

EXPECTATIONS AND EVALUATION

Students must complete a research project and write a paper to meet the requirements of the research course. We expect students to put in about 90 hours of time on their project and paper. They are given a syllabus with evaluation forms and the criteria by which both the research and paper will be evaluated. Students also receive a *Style Format for Senior Papers in Biology/Chemistry*. All students choose a research adviser at Asbury College even if they work elsewhere. The adviser is responsible for determining the student's course grade. This is done by an evaluation of the student's laboratory work (50% of grade) by the adviser and/or supervisor if done elsewhere. A rough draft of the research paper (10% of grade) must be submitted to the adviser. Upon completion, the paper is evaluated by the research adviser and one other faculty member for the remaining 40% of the grade. The senior papers are kept on file in our division office.

PROBLEMS AND DIFFICULTIES

The most serious problems originate with the unstructured nature of the research experience. Most of our students carry out a good research project. Some have obtained employment in laboratories because of the quality demonstrated while doing their research. The most rewarding comment we receive from employers is 'Do you have any more students like that.' However, there is always a minority of students lacking self-motivation who simply accomplish little in an unstructured environment. These students tend to avoid research at UK or other institutions; some of them we deliberately steer into research here so our students do not get a bad reputation at other institutions. Regular contact with the research adviser does help. In the Biology Department we have a policy that regular weekly meetings can be part of the course grade.

The Asbury College Library, although generous in purchasing scientific periodicals, is not fully adequate as a source of literature to support research. Students can do a computerized search at our library, but most students typically utilize the library at UK or some other institution.

Occasionally there is disagreement among the faculty about whether a particular project qualifies as independent scientific research. A small minority of projects could have been better described as reviews rather than original research.

Because of the inherent nature of research and where students do it, we have found it necessary to be flexible with the deadlines given in the course syllabus. Students frequently are given incomplete grades at the end of the fall term to allow additional time to complete the research and paper. Occasionally students who do research in summer or in a research semester elsewhere actually complete their research before taking the Introduction to Research course.

CONCLUSION

Although the process is time consuming and occasionally stressful, we feel that our undergraduate research program is a real asset. It provides students with an opportunity to understand the scientific method and scientific writing by actually doing them. They are well prepared to enter research if they attend graduate school. Some students have found their chosen field by the experience of doing research. Others have found employment in laboratories where they have demonstrated their competence. We are strongly convinced that our undergraduate research program is a success and should be continued.

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research Experiences at an Independent Cancer Research Institute

Julia H. Carter and Diane S. Collier

Wood Hudson Cancer Research Laboratory, 931 Isabella Street, Newport, Kentucky 41071

ABSTRACT

Wood Hudson Cancer Research Laboratory, an independent, not-for-profit [501(c)(3)] organization dedicated to the study and research of cancer, has a unique Undergraduate Research Education Program (UREP). UREP provides opportunities for students to learn research techniques and to develop critical thinking skills through "hands-on" participation in ongoing cancer research projects at the Laboratory. Student involvement in ongoing research at Wood Hudson Cancer Research Laboratory began in 1982; since then 108 students have participated in the program. The objective of UREP is to encourage undergraduate students to remain in biology and to go on to careers in science and medicine; therefore UREP addresses the nationally recognized problem of a decline in the interest of students for careers in science. UREP provides opportunities for undergraduate students to develop the skills identified by business and industry in Kentucky as being essential for all employees. Thus UREP serves not only as an introduction to biomedical research but also as a stepping stone from the undergraduate college laboratory to the world of research and development in a highly competitive global economy.

INTRODUCTION

Undergraduate research in the biological sciences offers an educational experience not only at colleges and universities but also at government agencies and not-for-profit research institutions throughout the United States (Russo 1997). Each institute of the National Institutes of Health of the U.S. Public Health Service offers a summer internship program. The U.S. Environmental Protection Agency also provides research experiences for undergraduates. Many of the 85 independent not-for-profit research institutions that are members of the Association of Independent Research Institutes (AIRI)—including the Whitehead Institute, the Oklahoma Medical Research Institute, the McLaughlin Research Institute for Biomedical Sciences, and Wood Hudson Cancer Research Laboratory (the only AIRI institution in Kentucky)—provide educational opportunities for undergraduates.

Student involvement in research at Wood Hudson Cancer Research Laboratory began in 1982 with three students. Wood Hudson's Undergraduate Research Education Program (UREP) facilitates student learning of research techniques and developing of critical thinking skills through "hands-on" participation in ongoing cancer research projects. In 1987, with financial assistance from the Ralph E. Mills Foundation (Frankfort, Kentucky) and the James Graham Brown Foundation (Louisville, Kentucky), UREP became part of the three-pronged mission of the Laboratory. To date, 108 students (ca. 16–22 students per year) from 19 colleges and universities have participated in UREP.

The objective of UREP is to give undergraduates "hands-on" experience in biomedical research and thereby to encourage them to remain in biology and to go on to careers in science and medicine. Of the UREP participants who remained in the biological science major and received the bachelor's degree, 94% have gone on to careers in scientific research, technology, science education, and medicine.

PROGRAM OVERVIEW

Statement of Need

In recent decades there has been a decline in the number of students planning to pursue careers in science and medicine. According to Frank H.T. Rhodes, President of Cornell University and member of the National Science Board, if this trend continues, by the first decade of the 21st century the United States may be faced with a 700,000-person shortfall in the number of technically trained individuals, in-

cluding 400,000 with the degree of Bachelor of Science (B.S.). The anticipated shortage of doctoral-level scientists may be as high as 9600 per year. As Dr. Rhodes stated, "shortages of this magnitude would be a crippling national handicap." Unfortunately, attrition rates from collegiate science programs are very high (Fort 1993). Undergraduates cite boredom with lectures as one reason for leaving science (Russo 1997).

American society and, indeed, the entire world community depend on increasingly complex technologies. More than 50% of the new laws passed by Congress involve an aspect of science or technology; continued increases in that percentage are expected (Shen 1975). The fact that American businesses must now compete, in a global economy, with nations whose youth often have received outstanding training in science and mathematics necessitates an American work force with technical expertise.

Because the nature of technical problems to be solved continues to change rapidly as knowledge advances, the successful workers of today and tomorrow must possess not only technical skills and mastery of facts but also the ability to "think like scientists." They must be able to think logically and critically, have a knowledge base that has integrated information from multiple fields of study, be able to apply mathematics in problem-solving, and be proficient in use of computers.

The study of science at the college level is compartmentalized into subject areas, such as biology, chemistry, physics, etc. Subjects are taught sequentially and in isolation from one another rather than concurrently and with recognition of interrelationships among various scientific disciplines. Furthermore, because of an emphasis on tests and test performance, rote learning and memorization—necessary but not sufficient components of science education—are the primary focus of many college science courses (Fisher 1992; Fort 1993). For instance, students may learn to "plug in" figures from a memorized formula, but they may not be able to determine when and why that particular formula should be used to solve a given problem (Michel 1993). Finally, college course work is, for the most part, not experientially based. Vice President Al Gore has remarked that "college students frequently have no clear conception of ways in which they can practice the science they are studying" (Gore 1992).

Studies by both the National Science Foundation (1986) and the American Council on Education (1985) have found that "hands-on" experience in active research is one of the most effective techniques for training undergraduates. According to Tobias (1990), college science courses (including introductory courses) designed to prepare students for careers in science should be experientially-based. Many practicing scientists and engineers began their careers in science through presently defunct undergraduate research programs. Today, although research experience is sought increasingly by employers in pharmaceutical and other industries, as well as by graduate and medical schools, undergraduate research experience has become difficult to obtain. To quote one student, "Everyone wants someone with experience but no one is willing to provide it."

In addition to "hands-on" experience and mastery of scientific facts, there is a third essential component of science education: the teaching of critical thinking skills. By working with knowledgeable scientists, students not only learn the technical skills involved in conducting an experiment, but also begin to learn how that scientist has designed the experiment to answer a particular question (as well as how he or she determined which question to ask), and, once the experiment is completed, how to analyze the data and interpret the results and how to identify new questions arising from those results. Furthermore, by experiencing the actual practice of science in ongoing research projects, students can experience the excitement of acquiring new knowledge through rigorous experimentation.

Finally, as Fort (1993) pointed out, approaching science and technology through "themes with clear social relevance" appears to be a promising strategy. Wood Hudson Cancer Research Laboratory approaches science education in exactly this fashion. In 1997 alone, more than 1.2 million new cancer cases will be diagnosed. Students working at Wood Hudson Cancer Research Laboratory are aware of the relevance and importance of their work to society.

Program Goals

The ultimate goal of UREP is to encourage college students to pursue careers in science and medicine. Intermediate goals are to provide opportunities for students to (a) learn specific laboratory techniques; (b) develop critical thinking skills; (c) participate in ongoing biomedical research serving a worthy purpose; (d) experience the excitement of scientific discovery by working with practicing scientists; (e) gain valuable work experience that will give them advantages when seeking employment or admission to graduate and professional schools; and (f) earn income that, in many cases, is needed for them to remain in college.

Program Objectives

To achieve the goals of the program, several objectives have been set. The first objective is to provide students in UREP with "hands-on" training and experience in specific laboratory techniques used in investigations of abnormal and normal cell and tissue structures and functions, including techniques of biochemistry, cell biology, histochemistry, immunohistochemistry, molecular biology (including DNA isolation), tissue culture, quantitative microscopy, and computer imaging.

The second objective is to introduce students in UREP to the practice of science (as opposed to study of scientific facts), including experimental design (necessity for controls, standards, adequate numbers of specimens, etc.), use of library resources, and preparation of data for publication. As part of learning the practice of science, UREP students are taught critical thinking and communication skills through interactions with practicing scientists conducting ongoing research projects and through student participation in weekly meetings of "journal club" (held to discuss and critique a current journal article).

The third objective is to increase student responsibility, self-accountability, and self-monitoring by providing structured laboratory experiences with progressive levels of student independence. In addition to laboratory safety policies, incoming students are required to become familiar with the Wood Hudson policies on scientific integrity. Computer skills, including effective use of word processing, spreadsheet, and relational database programs, are taught or reinforced.

The fourth objective is to provide a supportive yet intellectually demanding environment for learning. Competent practicing scientists, of both sexes, make themselves available for impromptu discussions of research problems and techniques and serve as role models. Although UREP participants come to the program with an interest in science and medicine, many report that their UREP experience has served as a stimulus for continuation of interest and involvement in research.

Finally, the program provides gainful employment for undergraduate science majors who are working their way through college. Generous, multi-year UREP support from 20 foundations, corporations, individuals, and government agencies has permitted Wood Hudson to pay UREP participants salaries that help to meet college expenses.

Job Description for Student Research Assistants

Student research assistants work where needed in research programs at the Laboratory; their assignments include both scientific and administrative laboratory work. Scientific laboratory work involves culture of mammalian cells, recombinant DNA procedures, biochemical assays (protein, DNA, and enzyme assays), cell fractionation techniques, histologic staining procedures, and computerized image analysis of microscopic sections. Administrative laboratory work includes assistance with preparation of grants, manuscripts, and literature searches. A *Procedures Manual* is provided to help students learn laboratory procedures used in experiments. Students also learn computer applications in word processing, spreadsheets, and statistical analysis.

Students should have as prerequisites some background in biological science and an interest in biological research. Generally, they should have 1 year of college biology and 1 year of college chemistry. They must be able to work carefully with scientific equipment and be accurate and precise in collecting and recording data. Finally, they must be able to work independently in collecting and studying published papers relevant to ongoing research projects.

Each of the students in the program works

10 hours per week at the Laboratory during the school year and 20 hours per week during the summer. Work schedules are flexible to accommodate exams and term papers. Students work a minimum of a 16-week semester; most students work in UREP for 1 or 2 years.

Students Served by UREP

UREP participants typically attend colleges and universities in the Greater Cincinnati/Northern Kentucky area (Xavier University, University of Cincinnati, Thomas More College, Northern Kentucky University) and/or are residents of the area. Many students who reside in the area attend colleges throughout the United States and participate in UREP during their summer breaks. To date, UREP has drawn 108 students from 19 colleges and universities across the United States. Most have begun in UREP as juniors or seniors, although a few have been freshmen or sophomores; two outstanding high school graduates were permitted to participate during the summer prior to their beginning college. Few have had prior exposure to a research environment.

Selection of students for participation is based upon recommendation of a professor, courses completed, and personal interviews. Students with the highest grade-point averages are not necessarily the most resourceful UREP participants. Each student is given a chance to prove himself or herself, but, once in the program, carelessness in technique or with data is unacceptable. Students are expected to be self-starters and to show intellectual curiosity about the work; a questioning attitude is strongly encouraged. Because women are under-represented in science (women comprise nearly half the work force but only 15% of practicing scientists), they are sought as participants in UREP. To date, nearly half (45%) of UREP students have been women. Members of minority groups are sought for the same reason. In addition, UREP students are often the first generation to attend college. Without exposure to research as undergraduates, these students might never see themselves as scientists.

STUDENT EVALUATIONS OF UREP

Students are asked to evaluate the program at least once a year. This permits adjustments to be made in emphasis and to ensure that the program continues to meet student needs. The following comments were selected from these evaluations to indicate, in students' own words, what UREP has meant to the participants. "I truly enjoy working at Wood Hudson because I learn interesting things about research in general, cancer specifically, and the actual techniques and procedures involved." "I feel that my position at Wood Hudson not only strengthened my application for acceptance to medical school but also strengthened my appreciation for scientific research." "Wood Hudson Cancer Research Laboratory has been my most rewarding job to date. The program has provided me with a general understanding of how research is done. I found this job rather inspiring for the goals I have set." "I have gained more knowledge this summer, through hands-on lab training, than I will ever hope to gain in the classroom alone." "My experience as a student research assistant at Wood Hudson Cancer Research Laboratory has been a great opportunity. . . . As I prepare to graduate and apply to graduate school in molecular biology, the work I have done at the Lab has given me the background I need." "I had begun to despair of ever gaining the experience that medical and graduate schools emphasize. I found myself running into the timeless problem: everyone wants someone with experience but no one is willing to provide it." "One of the things that I like about this program [UREP] is the independence that I am given. In the labs at college, students constantly have teaching assistants looking over their shoulders. Here, we are given the chance to spread our wings and try things for ourselves."

LONG-TERM FOLLOW-UP OF UREP PARTICIPANTS

While UREP provides gainful employment, its most valuable benefit is research experience for the students. Research experience is sought by graduate schools and employers in the pharmaceutical and other industries. As a result, UREP has been very successful in reaching its stated goals. Of the 66 participants who have completed the degree of Bachelor of Science to date, 94% have gone on to pursue careers or postgraduate courses in science and medicine. Four are practicing medicine locally and five are practicing in other states.

Twelve former UREP students are in master's or doctoral programs and nine have earned advanced degrees in a scientific discipline. Altogether, 71% of UREP participants who have earned the bachelor's degree have obtained postgraduate education. Many former UREP participants are currently employed by local pharmaceutical companies, university laboratories, hospitals, and other science-related organizations.

CONCLUSION

The objective of UREP is to encourage undergraduate students to remain in biology and to go on to careers in science and medicine; therefore UREP addresses the nationally recognized problem of a decline in the interest of students for careers in science. Success of UREP is measured by several criteria including (a) the percentage of UREP participants with the degree of Bachelor of Science who pursue careers in science and medicine; (b) student evaluations of UREP; (c) the number of times individual UREP students are associated with published (peer-reviewed) research, including authorship, presentation of research findings at scientific meetings, and citations for contributions to published work; (d) the number of students referred to the program by college biology department chairpersons; and (e) the number of students obtaining college credit for participation in UREP. During the past 16 years, UREP has been eminently successful as judged by these criteria.

As Kentucky participates in a global economy, businesses and industries within the state have identified several needs for all employees including area-specific skills (e.g., chemistry, mathematics, etc.), communication skills, interpersonal skills, problem solving, computer skills, organizational skills, and flexibility (Kiser 1997). UREP provides undergraduate students the opportunities to develop each of these skills. The Undergraduate Research Education Program at Wood Hudson Cancer Research Laboratory serves not only as an introduction to biomedical research but also as a stepping stone from the undergraduate college laboratory to the world of scientific research in a highly competitive global economy.

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Undergraduate Research in Kentucky: Biological Sciences

Encouraging New Biologists

Ross C. Clark

Department of Biological Sciences, Eastern Kentucky University, Richmond, Kentucky 40475

ABSTRACT

The world of the future will offer many opportunities for biological research. Eastern Kentucky University provides a supportive environment for undergraduate biology research and a faculty dedicated to student development. Student research projects focus on many topics, from the molecular to the ecosystem level. Involvement in research equips students with many skills and habits that are strong assets for successful careers.

INTRODUCTION

It has been said that the 20th century has been the century of physics and that the 21st will be the century of biology. This is an overgeneralization, of course. In the future, all areas of science will continue to uncover new insights and arrive at further syntheses of how the natural world functions. As new scientific insights and relationships emerge and the resulting technology advances, we can also confidently predict that ethical dilemmas will sharpen and we shall be forced into recasting our assumptions about our relationships with each other and with the other inhabitants of our planet.

Although these inevitable developments will result from integrating discoveries in all branches of science, they will devolve primarily from what is happening in biology. In a very short time, we have come from a grasp of Mendelian genetics to the point where we now argue only relatively fine points of evolution and map our own genome; from puzzling over the fossil record to constructing molecular phylogenies; from dependence on wild food sources and the jungle as "heart of darkness" to unalterable ecosystem fragmentation, habitat destruction, and a major planetary extinction episode; and from broad susceptibility to fatal diseases, to their control, and back to susceptibility.

Since there is considerable evidence that within the lifetime of our students the study of living systems will preoccupy us as never before, we should choose carefully the elements of training that will enable students to function effectively in a very different future. Involvement in research involving natural phenomena is what sets science apart from other disciplines. As such, it is essential training for all seriously aspiring biologists. Research, like the arts, requires both training and practice. Anyone with curiosity who can grasp complex relationships and procedures can do research, but a disciplined approach to the design, execution, and analysis of inquiry is most likely to produce meaningful results. The disciplined approach is best learned from example.

A DIVERSE LEARNING ENVIRONMENT

Although many important scientific advances have emerged under less than ideal conditions, providing a conducive environment is fundamental to encouraging research. Some Eastern Kentucky University (EKU) biology students come to us with a narrowly focused view of where they want to go, but many others come to us un-preprogrammed. We consider it our mission to maintain a supportive learning environment that gives students many choices of where to go in biology and the opportunities to develop themselves along whatever pathways they choose. Maintaining diversity in the learning environment is a key consideration.

We consider ourselves fortunate in that many of our students come from backgrounds where their curiosity has been piqued by lifelong casual observation of organisms; that is, they still retain meaningful connections to the natural world. The natural curiosity with which they arrive is congruent with the greatest strengths of our program. While we strive not to be a specialized department, we do

have an emphasis. The strength of EKU biology lies in field-based studies of adaptive behavior and relationships, ecosystem structure and function, and biodiversity. We believe there always will be a market for biologists who recognize and understand organisms and how they function in natural systems. In our program the molecular approach, instead of being an end in itself, is a powerful, essential tool to understanding.

We offer formal majors in biology, biology teaching, microbiology, environmental resources, wildlife management, aquatic biology, and cell and molecular biology. In addition, students may specialize in other areas (e.g., botany, zoology, premedical studies). To encourage faculty collaboration and students' individual choices, we are not organized into special interest departmental subgroups. Our 20 faculty members all have doctorates from different schools, which results in a variety of viewpoints, contacts, and collaborative arrangements useful for student development.

In addition to the normal core biology curriculum required for all undergraduate majors, we regularly offer 26 advanced courses that are available to undergraduates. A number of those courses include a required research component. Classes are limited in size; advanced undergraduate classes usually have fewer than 15 students enrolled. Advanced undergraduates often enroll in our formal undergraduate research courses, BIO 489 (Field Studies in Wildlife) and BIO 598 (Special Problems). These courses can be taken more than once for credit. A statistics course, providing the tools for assessing many experiments, is required for all undergraduate biology majors. In addition, we encourage student participation in Phi Sigma biology honorary; in our student chapter of the Wildlife Society; in our genetics, evolution, and molecular biology journal club (GEMS); and in Sigma Xi. This diverse learning environment encourages close student-to-faculty contact and the development of mentoring relationships, which often lead to participation in research.

We consider it our responsibility to give all of our majoring students encouragement and opportunity to do research. All wildlife management graduates are required to complete a formal research project. These studies often are of publishable quality. Even though our other degree programs do not specifically require formal research, we advise all students interested in continuing their studies past the bachelor's level that they should gain research experience. However, the choice is up to them. In fact, the majority of our graduating seniors have formal research experience.

THE RESEARCH ENVIRONMENT

Most undergraduate biology research at EKU is locally or regionally focused. A sampling of projects within the last 2 years (listed in no particular order) includes ecological and adaptive behavior studies on endangered bats and birds; habitat utilization studies of waterfowl, game, and non-game mammals; analysis of endangered goldenrod populations; predator-prey behavior in reptiles; effects of sewage on aquatic organisms; biodiversity surveys of aquatic organisms and vascular plants in disturbed and undisturbed ecosystems; population, mating, and nesting behavior of various bird species; chloroplast genome studies; and studies in isolation, structure, and diversity of respiratory enzymes. Additional similar studies and projects on waterborne microbial pathogens and adaptive behavior in fishes are in incipient stages.

While working on their projects, undergraduates either are guided by faculty members directly or work as members of teams involving faculty and one or more graduate students. Our student chapter of the Wildlife Society typically involves its members in several research projects during their undergraduate experience. In addition, students who show an interest are strongly encouraged to seek summer jobs involving research. Financial support for projects at EKU may come from several sources, including direct support from the department, university faculty development grants, or external grants and contracts. Faculty members typically include student support in the proposals they submit for grant and contract funding.

THE PAYOFF

We find that the opportunity to be personally involved in research is usually the main factor that propels students through the pivotal transition from passive learning to a different level of dedication to the study of biology. This is true whether they aspire to ca-

reers in medicine, other specialized biological fields, teaching, working in natural resource management agencies, environmental assessment, or many other career options.

Inexperienced students typically regard research as a potentially exciting but somewhat mysterious pursuit. Many are interested in trying it but are somewhat hesitant at the beginning. By actually doing research, they discover that behind every moment of revelation are many long hours in the field and/or laboratory doing rather repetitive and elementary tasks.

On the other hand, sustained involvement in research also teaches students to work cooperatively and patiently, to accept constructive criticism, to assess results and make judgments more carefully and independently than they ever have before, and to organize thoughts coherently and succinctly for presentation to others. In addition, they learn that to complete projects successfully, one must put in whatever time it takes: dedicated researchers often must work while others play. They learn that one must be clear about what questions one seeks to answer and that one must sometimes start again from the beginning to make necessary adjustments or to correct mistakes. If they work in a relaxed, supportive environment, they also learn that scientists, contrary to popular stereotype, interact in thoughtfulness and humor with other human beings. These lessons and habits invariably serve students well as they graduate to jobs and professional or graduate programs and as they later interact professionally with colleagues, their own students, administrators, and the general public.

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Undergraduate Research in Kentucky: Biological Sciences

Undergraduate Research Experiences in Biology at Murray State University and the Hancock Biological Station

Tom J. Timmons and David S. White

Department of Biological Sciences and Hancock Biological Station,
Murray State University, Murray, Kentucky 42071-0009

ABSTRACT

Undergraduate research experiences at Murray State University occur on campus in the broader aspects of biological sciences and at the Hancock Biological Station on Kentucky Lake (HBS) in the more focused area of ecosystem ecology. All biology faculty conduct research and are expected to mentor students informally or through formal undergraduate research courses. Students then are encouraged and given support to present their research results at local, regional, and national meetings and to publish in appropriate journals. HBS, in association with the Center of Excellence for Reservoir Research and a number of Federal grants, has provided unique undergraduate research opportunities. Since 1988 more than 100 students have received financial support while participating in research. Students attending HBS come not only from Murray State but also from throughout Kentucky and the eastern United States. Research experiences through the department and the station have made the participating students more competitive and successful when applying to graduate schools or entering careers.

The most effective way to understand the principles of research is to participate in all of its phases. Universities introduce students to the beginnings of science through experiments, creative laboratory research projects, and the web. But the true introduction to research comes in undergraduate research courses requiring independent study. Many students are surprised to discover that if anything can go wrong, it probably will: samples become contaminated in the growth chamber; half the fathead minnows die in the aquarium (often the control); the plants are overwatered and all die; someone stole all the artificial substrates from the stream. Undergraduate research provides students the first opportunities to actually develop hypotheses, develop methods to test the hypotheses, experiment, analyze the data, and then come to conclusions. Some students have their first experience with a literature review. They have to learn not only how to find the relevant literature but also how to critically evaluate what has been written.

Undergraduate research is not required of Murray State University (MSU) biology students, but we strongly encourage them to explore topics in their area of biology, particularly in their junior or senior years. Faculty members in biology at MSU average one student per year enrolled in our undergraduate research courses. Students can register for 1 to 4 hours of credit (BIO 491–BIO 494). The undergraduate research projects often result from interests developed in upper-level courses or interactions with other students actively involved with research. Students must find a professor with the equipment and facilities for the project. They are required to write a proposal within 2 weeks of the start of the semester describing the research and have it approved by the faculty member. A copy of the proposal is also filed with the chair of the Department of Biological Sciences. Students work closely with their professors, usually meeting at least weekly to discuss progress or problems. They may work daily in the laboratory, depending upon the nature of their research.

The entire faculty in the department is involved with research; therefore, there are many opportunities for students to interact. There is no course budget allocated for undergraduate research, so students must rely on supplies and equipment from faculty, and most faculty support undergraduate research

with supplies or funds already available from research grants. Faculty occasionally help students to write proposals to request funds from organizations such as Sigma Xi, the Scientific Research Society, or the Council for Undergraduate Research. Faculty may request funds to purchase equipment through MSU's Committee for Institutional Studies and Research. Many field projects can be done at little cost. For example, students can study fishes by just borrowing a seine or using available microscopes and equipment. Many behavioral studies can be done in the field with binoculars and patience.

Murray State University undergraduates have a unique opportunity to participate in research. The Hancock Biological Station (HBS) on Kentucky Lake, a component of the Department of Biological Sciences, has a primary mission to present students with opportunities for individualized instruction, independent research, and close interactions with researchers. No detailed records of undergraduate research at HBS were kept between 1972 and 1988, although we are aware that many students were part of research activities. Since the inception of the Center of Excellence for Reservoir Research (CRR) in 1988, undergraduate research is well documented.

HBS is a year-around research and teaching facility with state-of-the-art laboratories and equipment for environmental and ecological studies. There is a nationally recognized summer field program that attracts students and faculty from throughout the eastern United States. HBS serves as the base for the Ecological Consortium of Mid-America (ECOMA), a group of eight universities and colleges that use the station as a base of operation for field trips and research throughout the year. CRR provides funding for much of the infrastructure, conducts a long-term monitoring program on Kentucky Lake, and maintains an extensive regional ecological database. Undergraduates from MSU and other universities are integrated into each of the research components through hourly employment, research for credit, internships, and a modified research experience program for undergraduates.

Beginning students need to be able to observe and participate in an active research program prior to developing and pursuing individual research questions, which is a goal of the CRR program. CRR undergraduates help in collecting and analyzing data for long-term monitoring and in maintaining the database. In turn, the data and parts of the database are available for use by students for research questions. For example, our reservoir data were used by three undergraduates at Tennessee Tech this past semester. Parts of the database are often used by students who wish to use real-world data in advanced statistics.

From 1988 to the present, 56 undergraduates have received hourly wages through CRR. Many students work up to 20 hours per week during the academic year and up to 40 hours per week in summer. Training students to become proficient in the field and laboratory often takes up to 6 months or longer. Students also develop an understanding of the methods and goals of specific research projects. They are encouraged to ask questions and are allowed to progress at their own rates with mentoring from M.S. and Ph.D. graduate students, CRR professional staff, postdoctoral associates, and research faculty. About a third of these students have completed a semester or more of research for credit. Research for credit requires that the students consider the design of CRR programs and produce a well thought out research paper.

There has been a rapid growth of externally funded research at HBS over the past 10 years; the more seasoned and skilled students are often in demand to participate. External research has involved 8 to 10 students per year over the past 5 years. Most of these students enroll for research credit during the academic year or summer semester. Many summer students come from other universities with the goal of conducting research in a field setting, an experience not usually available at their home institutions. These students either are integrated into ongoing research at HBS or accompany their adviser who will be teaching or conducting summer research at the station.

There is a growing number of students from other universities who carry out their internship requirements at HBS. These students conduct research questions through a faculty mentor at HBS but enroll for credit at their home institutions. Included have been students from Center College, Long Island University, Kennesaw State, Southern Illinois Uni-

versity, Central Florida, University of South Florida, Austin Peay State University, and Madisonville Community College.

HBS/CRR plans to submit a grant proposal this coming year to the National Science Foundation to establish a Research Experiences for Undergraduates (REU) program. As a prelude to the proposal, we created our own "REU" program for one summer with excellent success. Six very promising undergraduates from throughout the midwest were selected from a pool of 21 applicants. Each student attended the American Society of Limnology and Oceanography meeting (at the beginning of the summer session). Learning from the presentations attended, each student designed and conducted a research experiment over the following 8 weeks. Four of the six students subsequently enrolled in advanced degree programs in aquatic ecology.

Undergraduate research projects often lead to posters, presentations, and publications. Recent papers (Dreves et al. 1996; King et al. 1989) and published abstracts (Derting et al. l995; Derting and Carter 1995) in this journal were the result of projects initiated by undergraduates. Undergraduate research has resulted in recent papers in other journals, e.g., *American Malacological Bulletin* (Blalock and Sickel 1996), *Canadian Journal of Zoology* (Derting and Noakes 1995), and *Journal of Mammalogy* (Derting and Bogue 1993). The list of oral and poster presentations by undergraduates is too lengthy to include here. Faculty encourage and help students travel to professional meetings to present papers; some meetings are limited to student presenters. For example, aquatic biology undergraduates travel to the Annual Fisheries Student Colloquium sponsored by the American Fisheries Society. Many of our undergraduates give papers at the annual meeting of the Association of Southeastern Biologists and state societies such as the Kentucky Academy of Science or the Tennessee Academy of Science. Many professional societies have state chapters that encourage students to give the first presentation. MSU and Austin Peay State University sponsor a biannual 2-day joint symposium on natural history of the lower Tennessee River basin. The meeting, held in the Land Between the Lakes, attracts faculty and students from throughout the midwest. The first day of the symposium highlights presentations by internationally known scientists. Undergraduates are then encouraged to present results of their research in sessions on zoology, botany, or ecology. Beyond the abstracts, students may publish their results in the symposium proceedings, gaining experience in writing and editing. Undergraduates also present papers at national meetings in association with results from research by professors.

Undergraduate and graduate student research is encouraged by the MSU chapter of Sigma Xi, which each year sponsors the Sigma Xi Research Symposium and Poster Competition day. Students conducting research in any science-related discipline across campus can compete. The event provides students with a forum to present research results and to have faculty evaluate the presentations and comment on the student work. An award for the Outstanding Undergraduate Research is presented at the Sigma Xi Annual Banquet.

Another great advantage of undergraduate research is the opportunity for undergraduates to travel to collect data or present papers and posters at national or regional meetings. Undergraduates interested in paleontology recently have had summer opportunities to travel to Kansas and Spain. Students interested in field ecology have enrolled in undergraduate research during the summer and traveled to Belize and Ecuador. Undergraduates in aquatic biology often travel to coastal field stations to study ocean communities. One of our faculty travels to the arctic each summer; he has involved undergraduate researchers. Many of our national societies provide travel or lodging assistance for students giving papers at distant locations. Even within colleges or departments, we work harder to find money for promising students who are presenting papers.

Faculty find undergraduate research a unique way to interact with students. The work may not always be recognized by the tenure and promotion committee or provide any release time for faculty, but we enjoy working with students, especially in our area of research. Research experience is the best way to mentor a student. After a student has graduated, and lectures have been forgotten, the research experience will be long remembered. The faculty member also will remember the

student and can write meaningful letters of recommendation.

The undergraduate research experience is important for both students and faculty. Students learn how to conduct all aspects of research; they discover if research is the field for them. Research allows students an opportunity to explore areas of interest in greater depth than any course can offer. Students who have a research background and are accepted to graduate school and other professional schools have an advantage over students without research experience. Students who do not become researchers also benefit. One student who traveled to Alaska is now a high school teacher and incorporates material on arctic tundra ecology in her science classes. Some of our students who conducted undergraduate research at HBS now bring their classes to HBS to study ecology or chemistry. Although faculty may benefit from an undergraduate project, the professional interaction between student and professor is most important. The mentoring experience affects students throughout their future career.

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Distributional Records for Fishes of the Coastal Plain Province, Ballard and McCracken Counties, in Western Kentucky

Michael G. Ryon

Environmental Sciences Division, Oak Ridge National Laboratory,
Oak Ridge, TN 37831

and

Brian A. Carrico

6146 Cougar Drive, Knoxville, TN 37921

ABSTRACT

One hundred and forty-two collections were made at 37 sites located on streams within the Coastal Plain Province, Ballard and McCracken counties, Kentucky, from 1990 to 1997. Most samples were taken near the Paducah Gaseous Diffusion Plant as part of its Biological Monitoring Program, but additional collections were made from six watersheds spanning the Ohio and Mississippi River coastal plain north of Mayfield Creek and west of the Clarks River. These collections include 112,722 specimens representing 71 species, 40 genera, and 15 families. Compared to published distributional information, the ranges of 59 species were expanded and three species were added to the stream fauna of this region. Included in these expanded ranges are new localities for the redspotted sunfish (*Lepomis miniatus*) and the black buffalo (*Ictiobus niger*), two species listed as threatened and of special concern, respectively, by the Kentucky State Nature Preserves Commission.

INTRODUCTION

The Paducah Gaseous Diffusion Plant (PGDP) has supported a Biological Monitoring Program for streams bordering its facilities since 1987 (Birge et al. 1990; Kszos 1994). This program includes a fish community task group that monitors the changes in fish communities in Big Bayou and Little Bayou creeks and compares these changes with communities in area streams (Kszos 1994, 1996a, 1996b; Kszos et al. 1994). As a result of this monitoring program, extensive fish survey information has been gathered by the Oak Ridge National Laboratory (ORNL) for the region since 1990. Published information on fish distributions in the immediate vicinity of PGDP was limited. Burr and Warren (1986) reported on distributions in the general area, but no specific distributional studies have reported on streams in this section of western Kentucky. Therefore, data generated for the monitoring study were supplemented by sampling in additional streams to provide a better understanding of the fish fauna of this region.

The PGDP is located in McCracken County within 6.3 km of the Ohio River (Figure 1). It lies within the Coastal Plain Province as defined by Burr and Warren (1986) with the local streams draining the Mississippi Alluvial, Eastern Gulf Coastal, and Tennessee River plains. This province is an area of lowland plains with only limited relief provided by rolling hills and minor ridges. The geology reflects a sedimentary origin dating back to the Cretaceous seas and includes loose deposits of gravel, sand, and clay (Burr and Warren 1986; Mengel 1965). Oxbows, sloughs, and swamps become more common and the stream channels become more entrenched adjacent to the Mississippi and Ohio rivers.

The province includes several streams that have been widely sampled, including Clarks River, Mayfield Creek, Obion Creek, Bayou de Chien, and Terrapin Creek (Burr and Warren 1986; Kuhajda and Warren 1985; Sisk 1969). Considerable effort has also been expended to sample Metropolis Lake, oxbows, small floodplain lakes, and main channels of the Ohio River and Mississippi River in this province (Burr and Mayden 1979; Burr and Warren 1986; Burr et al. 1990; Krumholz 1981; Pearson and Krumholz 1984; Rice et al.

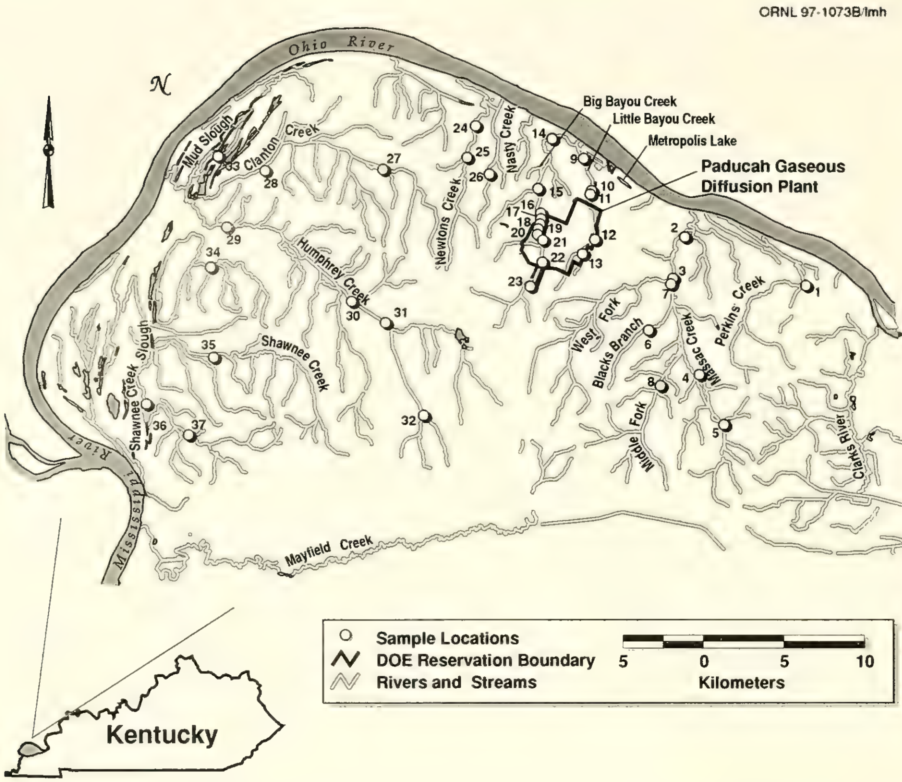

Figure 1. Streams in the Coastal Plain Province in McCracken and Ballard counties, Kentucky, and locations of fish-collection sites near the U.S. Department of Energy (DOE) reservation and the Paducah Gaseous Diffusion Plant (PGDP).

1983). However, the streams in McCracken and Ballard counties north of Mayfield Creek and west of the Clarks River have not been surveyed so extensively. Some of this lack of attention can be attributed to (1) the generally mundane appearance of the streams, (2) the considerable areas of habitat modification associated with agricultural activity, and (3) the restricted access for streams near PGDP. Major streams in this region include Perkins, Massac, Little Bayou, Big Bayou, Newtons, Clanton, Humphrey, and Shawnee creeks (Figure 1). These streams are west of the Tennessee River divide and flow into the Ohio River, except for Shawnee Creek, which enters the Mississippi River.

METHODS AND MATERIALS

Fish distribution surveys were conducted using backpack electrofishers in two standard procedures. When sampling was conducted as part of the quantitative PGDP biomonitoring, the electrofishing sample involved a three-pass removal estimate at standard sampling sites of ca. 100 m in length. For each sample, the sites were isolated by 0.64-cm-mesh seines, two or three backpack electrofishers followed by three to five netters were used to make upstream passes through the site, and all stunned fishes were removed for processing. Fishes were identified, measured, and returned alive to the sampling location. Voucher or verification specimens were taken for species unique to that location or for species particularly difficult to identify. Quantitative samples were collected on a spring and fall schedule at five standard sites.

When sampling was part of the qualitative biomonitoring, the electrofishing sample involved a single upstream pass through 100 to 200 m of stream or for a sampling effort of 1 to 2 hours. One or two backpack electrofishers

were used with two or three netters. Captured fishes were identified, counted (in most samples), and returned alive to the stream. Voucher specimens were taken as per the quantitative sites with additional specimens usually taken to represent each species present at the sampling location. Qualitative samples were made throughout the year, at various sites, from one to 11 times per site. Specimens were also obtained at a PGDP treatment lagoon during fish kill investigations. These specimens were retrieved using a small boat and dipnets.

All voucher specimens were preserved in 10% formaldehyde, washed, transferred to 60% ethanol, and cataloged in the ORNL Fish Reference Collection. Identification of unusual specimens was verified by Dr. David Etnier, University of Tennessee, Knoxville. All sampling was conducted following standard operating procedures (Schilling et al. 1996).

Descriptive ratings were used to categorize the distribution and abundance of individual species. Distribution categories, based on Smith (1965), include *generally distributed* (any suitable habitat within the area should yield species with sufficient collection effort), *occasional* (suitable habitat within the area may or may not yield species even after prolonged searches), and *sporadic* (the encountering of species cannot be predicted at all). Relative abundance was categorized following Ryon (1994) and included *rare* (one specimen taken per collection), *uncommon* (two to 20 specimens taken per collection), *common* (21 to 99 specimens taken per collection), and *abundant* (greater than 99 specimens taken per collection).

COLLECTION SITES

Collection sites were concentrated in the watersheds of Big Bayou, Little Bayou, and Massac creeks, but all major watersheds in the province were sampled. The following site descriptions include stream name, location of the sample site (stream kilometers to site from mouth of stream and position relative to map landmarks), county, and date(s) sampled. Relative locations are shown in Figure 1 with numbers indicating each sample site.

1. Perkins Creek at KY 305 (km 4.1), 0.6 km w of intersection of KY 45 and 358, McCracken County. Jul 1996.

2. Massac Creek at KY 1420 (km 3.2), 8.5 km w of Paducah, McCracken County. Jun 1992 and Jul 1996.

3. Massac Creek at KY 358 (km 6.4), 8.5 km w of Paducah, McCracken County. Jun 1993, Aug 1994, and Jul 1996.

4. Massac Creek at KY 62 (km 13.8), 5.5 km sw of Paducah, McCracken County. Thirteen occasions from Dec 1990 through Mar 1997.

5. Massac Creek at KY 339 (km 16.9), 8 km sw of Paducah, McCracken County. Jul 1996.

6. Blacks Branch at KY 1565 (km 2.0), 7 km w of Paducah, McCracken County. Jun 1993.

7. West Fork Massac Creek at confluence with Massac Creek (km 6.6), 0.3 km sw of KY 358 and 8.5 km w of Paducah, McCracken County. Jun 1993.

8. Middle Fork Massac Creek at KY 62 (km 2.4), 8 km sw of Paducah, McCracken County. Aug 1994.

9. Little Bayou Creek adjacent to settling ponds at the Tennessee Valley Authority's Shawnee Steam Plant (km 1.3), 11 km n of Future City, McCracken County. Jun 1992.

10. Little Bayou Creek at unnamed rd (km 4.3), 2 km w of KY 996 and 9.2 km n of Future City, McCracken County. Nine occasions from Dec 1990 through Apr 1996.

11. Tributary to Little Bayou Creek from PGDP outfall K003 (km 5.0), 8.1 km n of Future City, McCracken County. Dec 1990.

12. Little Bayou Creek at KY 358 (km 7.2), 6 km n of Future City, McCracken County. Twelve occasions from Dec 1990 through Mar 1997.

13. Little Bayou Creek at McCaw Rd (km 9.0), 5.2 km n of Future City, McCracken County. Ten occasions from Jun 1992 through Nov 1995.

14. Big Bayou Creek at Boldry Rd (km 2.8), 6.3 km ne of Ragland, McCracken County. Jun 1992 and Jul 1996.

15. Big Bayou Creek at KY 358 (km 6.9), 8.7 km ne of Kevil, McCracken County. Jun 1992.

16. Big Bayou Creek at unnamed rd (km 9.1), 0.9 km e of Bethel Church Rd, and 1.2 km sw of KY 358, McCracken County. Thirteen occasions from Dec 1990 through Mar 1997.

17. Big Bayou Creek at unnamed rd (km

9.4), 1.2 km e of Bethel Church Rd and 1.3 km sw of KY 358, McCracken County. Nine occasions from Nov 1993 through Nov 1995.

18. Tributary to Big Bayou Creek from PGDP outfall K001 (km 9.5), 1.4 km e of Bethel Church Rd and 1.3 km sw of KY 358. McCracken County. Nine occasions from Nov 1993 through Nov 1995.

19. Big Bayou Creek at unnamed rd (km 10.0), 3.3 km e of KY 725 and 1.7 km s of KY 358, McCracken County. Twelve occasions from Sep 1991 through Mar 1997.

20. C-611 Treatment Lagoons near Big Bayou Creek (km 10.1), 3.3 km e of KY 725 and 2.0 km s of KY 358, McCracken County. Jan 1992 and Mar 1992.

21. Big Bayou Creek at Water Works Rd (km 10.4), 3.7 km w of KY 996 and 2.5 km s of KY 358, McCracken County. Six occasions from Aug 1994 through Nov 1995.

22. Big Bayou Creek downstream of S. Acid Rd (km 12.5), 3.3 km w of KY 996 and 3.3 km s of KY 358, McCracken County. Thirteen occasions from Dec 1990 through Mar 1997.

23. Big Bayou Creek at KY 725 (km 14.5), 0.6 km w of intersection KY 725 and KY 1154, McCracken County. Jun 1992.

24. Newtons Creek at Grief Rd (km 4.4), 2.2 km n of KY 358, McCracken County. Dec 1990.

25. Newtons Creek at KY 358 (km 6.5), 12.2 km w of Metropolis, IL, McCracken County. Jul 1996.

26. Nasty Creek at KY 358 (km 5.0), 10.7 km sw of Metropolis, IL, McCracken County. Jul 1996.

27. Clanton Creek at KY 358 (km 13.8), 5.8 km se of Monkey's Eyebrow, Ballard County. Jul 1996.

28. Clanton Creek at Goose Haven Lane (km 5.7), 1.5 km n of Oscar, Ballard County. Jul 1996.

29. Humphrey Creek at KY 1105 (km 9.0), 2.7 km sw of Oscar, Ballard County. Apr 1996.

30. Humphrey Creek at KY 60 (km 20.4), 1.0 km ne of La Center, Ballard County. Dec 1990.

31. Humphrey Creek at Mosstown Rd (km 23.7), 3.3 km se of La Center, Ballard County. Apr 1996.

32. Humphrey Creek at Brookings Rd (km 30.8), 8.8 km se of La Center, Ballard County. Apr 1996.

33. Mud Slough at KY 310 (km 3.7), 3.3 km nw of Oscar, Ballard County. Jul 1996.

34. Hazel Creek at unnamed rd (km 7.8), 4.5 km n of Barlow, Ballard County. Jul 1996.

35. Shawnee Creek at KY 60 (km 7.1), 0.8 km s of Barlow, Ballard County. Apr 1996.

36. Shawnee Creek Slough at unnamed rd (km 5.0), 3.5 km w of KY 60 and 5.8 km sw of Barlow, Ballard County. Apr 1996.

37. Cane Creek at KY 60 (km 4.6), 6 km s of Barlow, Ballard County. Apr 1996.

ANNOTATED LIST OF SPECIES

Collections from these 37 localities yielded 112,722 specimens representing 71 species, 40 genera, and 15 families. For each species, the entry lists collection sites by number (see Figure 1) and, in parentheses, the number of specimens collected and the number of voucher specimens. Additional comments about unique habitats or conservation status are given when appropriate. Species names are based on guidelines in Etnier and Starnes (1993) and Robins et al. (1991). Comparisons to published literature refer to the distributional studies of Burr and Warren (1986), unless otherwise indicated.

LEPISOSTEIDAE—Gars

Lepisosteus oculatus (Winchell). Spotted gar. Sites: 2 and 28. (3 specimens collected and vouchered.) Not reported previously from Massac and Clanton creeks but has been found in the Ohio River near the mouth of Massac Creek and in Metropolis Lake.

Lepisosteus osseus (Linnaeus). Longnose gar. Site: 2. (1 large specimen collected and released.) Not reported previously from Massac Creek but has been taken from the Ohio River in the vicinity of Massac Creek and in Metropolis Lake.

Lepisosteus platostomus Rafinesque. Shortnose gar. Sites: 2, 28, and 33. (4 specimens collected; 3 vouchers.) Not reported previously from Massac Creek and Mud Slough but has been collected in the Ohio River, Metropolis Lake, and Clanton Creek.

AMIIDAE—Bowfins

Amia calva Linnaeus. Bowfin. Sites: 2, 14, and 16. (4 specimens collected and released.) Not reported previously from Big Bayou and Massac creeks.

CLUPEIDAE—Herrings

Dorosoma cepedianum (Lesueur). Gizzard shad. Sites: 2–4, 10, 14, 16–18, 20–22, and 27–29. (666 specimens collected; 64 vouchers.) Occasional and locally common in streams within the coastal plain.

Dorosoma petenense (Guenther). Threadfin shad. Site: 33. (1 specimen collected and vouchered.) Not reported previously from Mud Slough although many records exist for the Ohio River in that vicinity.

CYPRINIDAE—Carps and minnows

Campostoma anomalum pullum (Agassiz). Central stoneroller. Sites: 2–8, 10, 12–19, 21–23, 25–27, 30–32, 35, and 37. (44,831 specimens collected; 669 vouchers.) Abundant and generally distributed in Massac, Little Bayou, and Big Bayou creeks but less numerous and only occasional in other coastal plain watersheds. Not reported previously from Big Bayou, Little Bayou, and Clanton creeks.

Carassius auratus (Linnaeus). Goldfish. Site: 4. (1 specimen collected and released.) Not reported previously from Massac Creek.

Ctenopharyngodon idella (Valenciennes). Grass carp. Site: 17. (1 specimen collected and vouchered.) Not reported previously from any tributaries of the Ohio River in the Coastal Plain Province north of Mayfield Creek although records from the Ohio and Mississippi rivers were known. Our specimen was probably an escapee from fishing ponds located on the Western Kentucky Wildlife Management Area (WKWMA) where the species has been stocked for control of aquatic vegetation.

Cyprinella lutrensis (Baird and Girard). Red shiner. Sites: 2–4, 7–10, 12–22, 27, 30, and 31. (2853 specimens collected; 552 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks but considered common and generally distributed in small tributaries to the lower Ohio River.

Cyprinella spiloptera (Cope). Spotfin shiner. Sites: 2, 3, 7, 9, 10, 14, 15, and 28. (120 specimens collected; 117 vouchers.) Not reported previously west of the Clarks River. Our specimens represent the first verified records from the Coastal Plain Province in Kentucky. The absence of spotfin shiners from coastal plain ecoregions was also noted for Missouri (Pflieger 1975) and Tennessee (Etnier and Starnes 1993), although Smith (1979) documented their presence in lowland areas of Illinois. The spotfin shiner usually occurred in collections with the steelcolor shiner, although they were not as common or as widely distributed. Four hybrid specimens between these two *Cyprinella* species were also taken.

Cyprinella whipplei Girard. Steelcolor shiner. Sites: 2-4, 7, 10, 12, 14–17, 19, and 22. (650 specimens collected; 493 vouchers.) Not reported previously from Big Bayou Creek. Generally distributed and common in Massac and Big Bayou creeks but only occasional in Little Bayou Creek.

Cyprinus carpio Linnaeus. Common carp. Sites: 1–4, 10, 14, 16–18, 28–31, and 33. (53 specimens collected; 35 vouchers.) Not reported previously from Perkins, Massac, Big Bayou, Little Bayou, Clanton, and Humphrey creeks. Generally occasional in distribution and uncommon at a specific site.

Hybognathus nuchalis Agassiz. Mississippi silvery minnow. Sites: 1–4, 7, 9, 10, 12, 14, 16, 17, 19, 22, 25, 27, and 29. (3358 specimens collected; 716 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Generally distributed and locally abundant when found in its preferred habitat of slow runs and shallow pools with sand or soft substrates.

Lythrurus fumeus (Evermann). Ribbon shiner. Sites: 3, 4, 7, 9–12, 14, 16, 17, 22, and 28–30. (604 specimens collected; 272 vouchers.) Not reported previously from Big Bayou, Little Bayou, Clanton, and Humphrey creeks. Generally distributed in the province but usually uncommon at specific sites.

Lythrurus umbratilis (Girard). Redfin shiner. Sites: 3, 4, 9–13, 16–19, 21, 22, 25, 29–31, and 35. (1343 specimens collected; 324 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Generally distributed throughout the province and often common to abundant at specific locations.

Macrhybopsis storeiana (Kirtland). Silver chub. Site: 29. (1 specimen collected and vouchered.) Not reported previously from Humphrey Creek but reported from the Ohio and Mississippi rivers in the Coastal Plain Province.

Notemigonus crysoleucas (Mitchill). Golden shiner. Sites: 1–4, 7, 10, 12–14, 16–18, 21, 22, 25–30, and 34-36. (198 specimens collected;

36 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Although its distribution was widespread, numbers were generally uncommon at most sites.

Notropis atherinoides Rafinesque. Emerald shiner. Sites: 2, 10, 20, and 29. (55 specimens collected and vouchered.) Distribution was sporadic and usually rare to uncommon in our samples. The species prefers larger streams and rivers, which were not sampled intensively in these collections.

Notropis blennius (Girard). River shiner. Site: 10. (9 specimens collected and vouchered.) Not reported previously from tributaries to the Ohio River in the Coastal Plain Province. Its preference for larger rivers would indicate that our specimens were transients in lower Little Bayou Creek.

Notropis stramineus (Cope). Sand shiner. Site: 10. (1 specimen collected and vouchered.) Not reported previously from tributaries to the Mississippi and lower Ohio rivers except for Mayfield Creek. Generally uncommon or absent from lowland tributaries in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993).

Notropis volucellus (Cope). Mimic shiner. Site: 3. (1 specimen collected and vouchered.) Not reported previously from tributaries to the Ohio River in the Coastal Plain Province of Kentucky. Infrequently seen in coastal plain streams of Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993).

Phenacobius mirabilis (Girard). Suckermouth minnow. Sites: 3, 4, 7, 10, 12–14, 16–19, 22, and 30. (537 specimens collected; 105 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Only occasional with most samples having uncommon numbers per collection.

Pimephales notatus (Rafinesque). Bluntnose minnow. Sites: 2–10, 12–14, 16–19, 21, 22, 25, 27, and 29–32. (7897 specimens collected; 812 vouchers.) Not reported previously from any tributaries of the Ohio River in the Coastal Plain Province west of Massac Creek. Generally distributed and common to abundant in our collections.

Pimephales promelas Rafinesque. Fathead minnow. Sites: 4, 12, 19, and 22. (59 specimens collected; 14 vouchers.) Sporadic and uncommon in Big Bayou and Massac creeks. Not reported previously in any streams west of Clarks River and north of Mayfield Creek. Its rarity or absence in coastal plain streams of neighboring states was also noted by Etnier and Starnes (1993), Smith (1979), and Pflieger (1975). Specimens may have been introduced into Little Bayou and Big Bayou creeks by fishing activities associated with numerous small ponds on WKWMA.

Pimephales vigilax (Baird and Girard). Bullhead minnow. Sites: 2, 3, and 29. (52 specimens collected and vouchered.) Not reported previously from tributaries in the Coastal Plain Province north of Mayfield Creek; sporadic in our samples. This sporadic distribution for the bullhead minnow in coastal plain streams of Kentucky contrasts greatly to its distribution in similar habitats in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993), where it was widely distributed and often very abundant.

Semotilus atromaculatus (Mitchill). Creek chub. Sites: 4–6, 8–10, 12, 13, 16–19, 21–25, 27, 29–32, 35, and 37. (5355 specimens collected; 45 vouchers.) Not reported previously from Big Bayou, Little Bayou, and Clanton creeks. Generally distributed and more common in small streams and the upper reaches of larger watersheds.

CATOSTOMIDAE—Suckers

Carpiodes carpio (Rafinesque). River carpsucker. Sites: 2 and 16. (4 specimens collected; 2 vouchers.) Not reported previously for any tributaries to the Ohio River in the coastal plain, but several collections are listed for the Ohio River in the vicinity of Massac Creek.

Carpiodes cyprinus (Lesueur). Quillback. Sites: 2 and 3. (4 specimens collected and vouchered.) Not reported previously from coastal plain tributaries of Kentucky; primarily a large stream and river species. Also rare in coastal plain streams in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993) with most records occurring in larger rivers. Our specimens ranged in size from 8 to 17 cm TL, suggesting that young and juvenile quillback may use the lower reaches of coastal tributaries for rearing and feeding areas.

Catostomus commersoni (Lacepede). White sucker. Sites: 3, 4, 6–8, 12, 16, 17, 19, 21, 22, and 30–32. (99 specimens collected; 13 vouch-

ers.) Within the province, reported previously only from Massac Creek. Occasional and uncommon in our samples. The widespread distribution of the white sucker in coastal plain streams of Kentucky contrasts with its distribution in coastal plain streams of and Missouri (Pflieger 1975) and Tennessee (Etnier and Starnes 1993) where it was absent or restricted to a few drainages.

Erimyzon oblongus (Mitchill). Creek chubsucker. Sites: 2–13, 16–19, 21–23, 25, 27, 29–32, and 35–37. (905 specimens collected; 65 vouchers.) Reported previously from streams of the Coastal Plain Province; locally common in our samples.

Ictiobus bubalus (Rafinesque). Smallmouth buffalo. Sites: 1–3, 16, 28, and 33. (48 specimens collected and vouchered.) Not reported previously from Perkins, Big Bayou, and Massac creeks but present in a few other Coastal Plain Province streams. As with other buffalo species taken in our samples, the majority of specimens were juveniles (mean = 5.3 cm TL), indicating that the coastal streams are used as nursery or rearing grounds for many of the fishes of the Ohio River in this province.

Ictiobus cyprinellus (Valenciennes). Bigmouth buffalo. Sites: 1–3, 16, 17, and 27. (29 specimens collected; 15 vouchers.) Not reported previously from Massac and Big Bayou creeks. Most of our specimens were from deep pools in medium to large streams, although juveniles were taken in a small shallow section of upper Clanton Creek.

Ictiobus niger (Rafinesque). Black buffalo. Sites: 2, 10, 16, 17, and 27. (9 specimens collected and vouchered.) Not reported previously from Massac, Big Bayou, and Little Bayou creeks. Generally considered rare in coastal plain areas of Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993). Because of its limited distribution, the black buffalo is listed as special concern for Kentucky (KSNPC 1996; Warren et al. 1986). Our specimens were taken from pools or backwater areas in medium to large streams over clay and sand substrates. A few, larger specimens (up to 26 cm TL) were collected, suggesting the coastal tributaries are used for more than just rearing areas.

Minytrema melanops (Rafinesque). Spotted sucker. Sites: 2–4, 10, 13, 15–17, 19, 29, and 30. (132 specimens collected; 16 vouchers.) Not reported previously from Little Bayou, Big Bayou, and Humphrey creeks. Occasional but uncommon in our collections.

Moxostoma duquesnei (Lesueur). Black redhorse. Sites: 3 and 4. (16 specimens collected and released.) Not reported previously west of the Clarks River in any coastal plain stream in Kentucky; generally absent from coastal plain streams in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993). In our sampling, the black redhorse occurred in Massac Creek sites over gravel and sand substrates in deep pools. Massac Creek, the most upland stream in the Coastal Plain Province, includes more typical black redhorse habitat than other watersheds. The specimens were encountered in two separate sampling events (1991 and 1993); most were large specimens (26 to 32 cm TL) identified in the field by lateral-line scale counts and body shape. Repeated efforts to obtain voucher specimens in later collections were unsuccessful, so these records should be considered suspect but not impossible given our success in documenting new locations for other sucker species.

Moxostoma erythrurum (Rafinesque). Golden redhorse. Sites: 2–4, 7, 8, 10, 15, 16, and 21. (145 specimens collected; 43 vouchers.) Not reported previously from coastal plain streams west of Massac Creek and north of Mayfield Creek. Occasional and uncommon in our samples. As with black redhorse, the golden redhorse was generally absent from coastal plain streams in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993).

ICTALURIDAE—Bullhead catfish

Ameiurus melas (Rafinesque). Black bullhead. Sites: 3, 10, 12, 16, 17, 19, 21, 22, 27, 28, and 36. (34 specimens collected; 12 vouchers.) Not reported previously from Big Bayou Creek.

Ameiurus natalis (Lesueur). Yellow bullhead. Sites: 2–6, 8–10, 12–19, 21–23, 25–31, 33, and 35. (1655 specimens collected; 74 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Generally distributed and common in our sampling, occurring from small tributaries to the largest streams.

Ameiurus nebulosus (Lesueur). Brown bull-

head. Site: 28. (3 specimens collected and vouchered.) Not reported previously in Clanton Creek. This location was a typical lowland stream habitat, with soft mud substrates. Specimens of all three bullhead species were taken in this sample. The limited distribution of brown bullheads in this province of Kentucky is very similar to the distribution in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993), where the brown bullhead was also the least common of the three bullhead species.

Ictalurus punctatus (Rafinesque). Channel catfish. Sites: 2, 3, 14, and 29. (8 specimens collected; 7 vouchers.) Not reported previously from Massac and Big Bayou creeks.

Noturus gyrinus (Mitchill). Tadpole madtom. Sites: 3, 9, 10, and 29. (9 specimens collected; 7 vouchers.) Not reported previously from Little Bayou Creek.

Noturus nocturnus Jordan and Gilbert. Freckled madtom. Sites: 2 and 14. (7 specimens collected and vouchered.) Not reported previously from tributaries in the coastal plain north of Mayfield Creek. Restricted to sites adjacent to the Ohio River in our sampling.

ESOCIDAE—Pikes

Esox americanus vermiculatus Lesueur. Grass pickerel. Sites: 2–4, 7, 10, 14, 16, 19, 29, 34, and 36. (43 specimens collected; 12 vouchers.) Not reported previously from Little Bayou, Big Bayou, and Humphrey creeks. Occasional but usually uncommon in our sampling.

APHREDODERIDAE—Pirate perches

Aphredoderus sayanus (Gilliams). Pirate perch. Sites: 1–4, 8–10, 12–16, 19, 21, 22, 25, 28–31, 33, 34, and 36. (281 specimens collected; 37 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Generally distributed and locally common in our sampling.

CYPRINODONTIDAE—Killifishes

Fundulus olivaceus (Storer). Blackspotted topminnow. Sites: 2–6, 8–10, 12–19, 21–23, 25–27, 29–33, and 35–37. (8892 specimens collected; 121 vouchers.) Reported previously from all coastal plain streams. Generally distributed, usually common, and locally abundant in our samples.

POECILIIDAE—Livebearers

Gambusia affinis (Baird and Girard). Western mosquitofish. Sites: 1–5, 8–10, 12–17, 19, 21, 22, 25–31, and 33–36. (4199 specimens collected; 126 vouchers.) Occasional and locally common in Coastal Plain Province streams.

ATHERINIDAE—Silversides

Labidesthes sicculus (Cope). Brook silverside. Sites: 2–4, 33, and 36. (14 specimens collected; 11 vouchers.) Occasional in the coastal plain streams, usually associated with larger streams.

PERCICHTHYIDAE—Temperate basses

Morone chrysops (Rafinesque). White bass. Sites: 2, 3, 28, and 29. (15 specimens collected and vouchered.) Not reported previously from Massac and Humphrey creeks.

Morone mississippiensis Jordan and Eigenmann. Yellow bass. Sites: 2, 29, and 33. (4 specimens collected and vouchered.) Not reported previously from Massac and Humphrey creeks.

CENTRARCHIDAE—Sunfishes

Centrarchus macropterus (Lacepede). Flier. Sites: 3, 10, 12, 14, 16, 17, 21, 25, 26, 34, and 36. (53 specimens collected; 8 vouchers.) Not reported previously from Massac, Big Bayou, and Little Bayou creeks.

Lepomis cyanellus Rafinesque. Green sunfish. Sites: 2–6, 8–10, 12–23, 25–31, 33, and 35. (3994 specimens collected; 52 vouchers.) Reported previously from all Coastal Plain Province streams. Occasional and locally common in our sampling.

Lepomis gulosus (Cuvier). Warmouth. Sites: 2–4, 8–10, 12–16, 19, 21, 22, 25, 26, 28–31, 34, and 36. (206 specimens collected; 20 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Occasional and usually uncommon in our sampling.

Lepomis humilis (Girard). Orangespotted sunfish. Sites: 10, 17, 28, and 33. (16 specimens collected; 13 vouchers.) Not reported previously from Big Bayou Creek. Sporadic and rare in our sampling.

Lepomis macrochirus Rafinesque. Bluegill. Sites: 2–6, 8–23, 26, 28–33, and 36. (2556 specimens collected; 68 vouchers.) Reported previously from all Coastal Plain Province

streams. Generally distributed and abundant in our sampling.

Lepomis megalotis (Rafinesque). Longear sunfish. Sites: 2–6, 8–23, 27–31, 33, and 36. (19,242 specimens collected; 148 vouchers.) Reported previously from all Coastal Plain Province streams. Generally distributed and abundant in our sampling.

Lepomis microlophus (Guenther). Redear sunfish. Sites: 9, 10, 14, 16, 21, and 28–30. (37 specimens collected; 5 vouchers.) Not reported previously from Big Bayou, Little Bayou, and Clanton creeks.

Lepomis miniatus Jordan. Redspotted sunfish. Sites: 10, 12, 14, 29, and 36. (7 specimens collected; 5 vouchers.) Not reported previously (under spotted sunfish, *Lepomis punctatus*) from Big Bayou, Little Bayou, and Humphrey creeks. This species is recognized as a threatened species in Kentucky (KSNPC 1996; Warren et al. 1986). Our specimens were collected in a variety of stream habitats: small to large streams, over clay, sand or rock substrates, in shallow streams (<30 cm depth) or in deep pools (>1 m depth), and in turbid or clear water. In most samples, they were found in areas of slower velocity near pools or deeper sloughs. The sporadic distribution and rare to uncommon abundance of redspotted sunfish throughout the Coastal Plain Province support its threatened status. The variety of habitats in which the species was found, however, suggests that it may be flexible in habitat preferences.

Micropterus punctulatus (Rafinesque). Spotted bass. Sites: 2–4, 7–13, 15–19, 21, 22, and 30. (517 specimens collected; 41 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks.

Micropterus salmoides (Lacepede). Largemouth bass. Sites: 1–5, 9, 10, 12–14, 16, 17, 19, 21–23, 25, 27–29, 31, 33, and 34. (281 specimens collected; 56 vouchers.) Reported previously from all Coastal Plain Province streams.

Pomoxis annularis Rafinesque. White crappie. Sites: 2, 3, 14–16, 18, 21, and 30. (28 specimens collected; 14 vouchers.) Not reported previously from Big Bayou and Massac creeks.

Pomoxis nigromaculatus (Lesueur). Black crappie. Sites: 2, 28, 33, and 36. (29 specimens collected and vouchered.) Not reported previously from Massac Creek.

PERCIDAE—Perches

Etheostoma asprigene (Forbes). Mud darter. Sites: 2, 10, 14, 29, and 36. (34 specimens collected; 31 vouchers.) Not reported previously from Massac, Big Bayou, Little Bayou, and Humphrey creeks. Sporadic but could be common locally in our sampling.

Etheostoma chlorosomum (Hay). Bluntnose darter. Sites: 3, 4, 10, 12, 14, 22, 28, 29, and 36. (79 specimens collected; 35 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Sporadic and generally uncommon in our sampling.

Etheostoma gracile (Girard). Slough darter. Sites: 3–5, 8–10, 12–14, 16, 18, 19, 22, 25, 28, 32, 33, 36, and 37. (315 specimens collected; 70 vouchers.) Not reported previously from Big Bayou and Little Bayou creeks. Occasional in our sampling but could be common at certain sites.

Perca flavescens (Mitchell). Yellow perch. Site: 14. (1 specimen collected and vouchered.) Not reported previously in the Coastal Plain Province or any streams west of the Tennessee River in Kentucky. Our specimen was a juvenile (5.5 cm TL) at a site within 3 km of the Ohio River. The distribution of yellow perch in neighboring states is also limited, with no records in coastal plain tributaries of Illinois (Smith 1979), Missouri (Pflieger 1975), or Tennessee (Etnier and Starnes 1993).

Percina caprodes (Rafinesque). Logperch. Sites: 2–5, 10, 19, and 33. (85 specimens collected; 17 vouchers.) Not reported previously from Massac, Big Bayou, and Little Bayou creeks. Sporadically distributed and generally uncommon in our sampling. In coastal plain streams in other states, the logperch is absent or rare in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993).

Percina maculata (Girard). Blackside darter. Sites: 3, 4, and 7. (53 specimens collected; 11 vouchers.) Not reported previously from tributaries to the Ohio River in the Coastal Plain Province in Kentucky; our specimens in Massac Creek represent the first in this region. Although not listed by Burr and Warren (1986), the blackside darter was reported from Obion Creek, a tributary to the Mississippi

River (Smith and Sisk 1969). The species was also found infrequently in coastal plain sampling in Illinois (Smith 1979), Missouri (Pflieger 1975), and Tennessee (Etnier and Starnes 1993), where it was becoming less widely distributed. Locally common in our sampling; most frequently collected over gravel and sand substrates in runs and shallow pools.

Percina shumardi (Girard). River darter. Site: 2. (1 juvenile specimen (3.6 cm TL) collected and vouchered.) Not reported previously from tributaries to the Ohio River in the coastal plain. Absent from the coastal plain of Illinois (Smith 1979), confined to larger channels of direct tributaries to the Mississippi River in Tennessee (Etnier and Starnes 1993), but common in tributaries in Missouri (Pflieger 1975).

Stizostedion canadense (Smith). Sauger. Site: 2. (13 specimens collected and vouchered.) Not reported previously from tributaries to the Ohio River in the Coastal Plain Province. Our specimens were juveniles and were common in the one collection.

SCIAENIDAE—Drum

Aplodinotus grunniens Rafinesque. Freshwater drum. Sites: 2, 20, and 33. (7 specimens collected; 3 vouchers.) Not reported previously from Big Bayou Creek, Massac Creek, and Mud Slough.

DISCUSSION

Many of the species discussed have not been reported previously from specific stream locations in the coastal plain (Burr and Warren 1986). However, their occurrence in the general area was inferred based on habitat preferences and known localities within the Ohio River, Mississippi River, or some tributaries in the Coastal Plain Province. Our sampling record provides details on exact stream locations for many species and adds three species to the known fauna of the area. The spotfin shiner, black redhorse, and yellow perch were not reported previously from the Coastal Plain Province in Kentucky. In our sampling, the spotfin shiner was occasional in the province, occurring in several larger streams. The black redhorse was found only in Massac Creek and was generally uncommon.

Our sampling also extended the known range for eight species from just the large rivers to include smaller tributaries in the Coastal Plain Province. The threadfin shad, grass carp, river shiner, mimic shiner, river carpsucker, quillback, sauger, and river darter were not reported previously from coastal streams or tributaries to the Ohio River. Most of these species are more commonly associated with large-river habitats, which would partially explain their rarity in the sampled streams, while the grass carp is an introduced species whose range is being expanded by the activities of people.

An additional 14 species were found in new locations in the Coastal Plain Province north of Mayfield Creek and west of the Clarks River, where previously they had been known only from the large rivers and/or one other locality such as Metropolis Lake, Mayfield Creek, Obion Creek, or Massac Creek. These species included spotted gar, goldfish, ribbon shiner, sand shiner, fathead minnow, bullhead minnow, bluntnose minnow, white sucker, spotted sucker, golden redhorse, brown bullhead, freckled madtom, blackside darter, and logperch. The bluntnose minnow, white sucker, spotted sucker, and golden redhorse were reported previously only from Massac Creek; all of these species are more widespread in the coastal plain.

Additional locations are also documented for the black buffalo and redspotted sunfish, species designated as being rare in Kentucky (KSNPC 1996). These species were collected in low numbers but in a variety of streams, indicating that their presence may be more widespread in the Coastal Plain Province than previously thought. Many of these new records are a result of repeated sampling at set locations rather than single collections spread over a wide area. Also the use of electrofishing gear probably resulted in more efficient collection of larger fishes, such as the sucker species.

The 71 species recorded in our study represent 69% of the species reported by Burr and Warren (l986) for this area of the coastal plain. The majority (78%) of the species we did *not* find are primarily species of large rivers and would be encountered with less frequency in the streams that were the focus of most of our effort. Some of the species we did not find—e.g., pugnose minnow (*Opsopoeodus emiliae*) and blackstripe topminnow (*Fun-*

dulus notatus)—are more common in smaller streams and bayous and are usually associated with aquatic vegetation, a cover type not frequently encountered in our sampling. Other stream species that are listed for this area of the coastal plain, but that we did not find, include several species listed as threatened or of special concern (KSNPC 1996); their rarity may be responsible for our failure to locate them.

The collection records also provide useful information on the general nature of the watersheds within the Coastal Plain Province. Although there was much overlap in species common to all of the streams, the larger systems had unique species within their fish communities.

Massac Creek differs from most streams within the Coastal Plain Province. Although structurally similar to the other streams, it does tend to have the highest gradients in the region. This might explain the occurrence of several species that might be considered atypical for the province. For example, both the black redhorse and blackside darter occurred only in Massac Creek; the typical habitat for these species is more upland in character than that found in most streams in the coastal plain. Also, there are many species more common in upland streams (e.g., golden redhorse and logperch) that occur with greater frequency in Massac Creek than in other streams. Conversely, species more typical of lowland streams (e.g., flier, orangespotted sunfish, and mud darter) occur at lower frequencies or are absent in Massac Creek. These collection records reinforce the designation of Massac Creek as part of the Tennessee River Plain (Burr and Warren 1986) with a mixture of both upland and lowland species. Massac Creek had the greatest number of species, 60, in our collections of coastal plain streams.

Big Bayou and Little Bayou creeks, more lowland in character than Massac Creek, have some species reflecting the influence of the recreational fisheries of the WKWMA. The presence of the grass carp and fathead minnow is likely to be a result of such management activity. The presence of the two protected species in the watershed also suggests that impacts associated with the PGDP may be quite limited and restricted to areas immediately adjacent to outfalls or to brief periods when streams conditions are unfavorable; it also demonstrates the value of the watershed for species diversity within the province. The similar number of total species in this watershed (50 species in Big Bayou Creek and 33 species in Little Bayou Creek) compared to others in the province (38 species in Humphrey Creek and 33 species in Clanton Creek) reinforces this conclusion.

The impact of other activities in the province was demonstrated substantially by the reduced faunas in some areas of Newtons and Perkins creeks, where total numbers of species were only 17 and 8, respectively. One survey of Newtons Creek was limited to one specimen of one species. This reduced fish community may be due to agricultural impacts such as high levels of sediment associated with runoff from fields, reduced riparian cover, and channelization of stream sections. The possible input of pesticides, herbicides, or fertilizers with resulting impacts on the fish communities also cannot be discounted. Perkins Creek has been impacted by urban developments such as sewage discharges. This stream was similar in size and habitat to parts of Massac Creek but contained far fewer species (8) than the mean number of species (20) for a comparable site in Massac Creek.

In general, the fish fauna of the northern section of the Coastal Plain Province was quite diverse given the limited habitat complexity of the lowland streams. This diversity was also evident when compared to coastal plain streams in Illinois, Missouri, and Tennessee where many of the species found in our surveys were absent or present at only a few locations. The influence of the large rivers bordering the coastal plain was great, with many species collected in our surveys represented only by juveniles, which may be utilizing the tributaries for feeding or rearing areas. We also noted a connection between flooding or elevated flows in the Ohio River and an increased number of specimens and species at some sites where samples where taken at regular intervals. The role of the smaller tributaries in coastal plain streams should include that of safe haven during such periods of stress in the main river. Many species in our sampling were represented by only one or a few specimens, indicating that further sampling

would probably continue to add to the species record.

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Distribution and Population Estimates of the Federally Endangered Relict Darter, *Etheostoma chienense*, Bayou du Chien, Kentucky

Kyle R. Piller[1] and Brooks M. Burr

Department of Zoology, Southern Illinois University at Carbondale, Carbondale, Illinois 62901

ABSTRACT

The relict darter, *Etheostoma chienense,* is a federally endangered species endemic to upper reaches of the Bayou du Chien drainage of western Kentucky. Between fall 1994 and spring 1996 we conducted a study to determine present distribution and to assess population size and abundance of *E. chienense.* Sixteen of 28 sites sampled harbored *E. chienense.* Estimates of the total drainage-wide population were between 9533 and 31,293 individuals. The species was considered common to abundant at five sites but rare or uncommon at the remaining 11. Length-frequency estimates revealed four age classes; age groupings reported here are comparable to what has been reported for other species of *Etheostoma* subgenus *Catonotus.*

INTRODUCTION

Etheostoma subgenus *Catonotus* (Pisces: Percidae) includes 17 described species common in rocky strewn headwater streams of eastern North America (Braasch and Mayden 1985; Jenkins and Burkhead 1993; Kuehne and Barbour 1983; Page 1983; Page et al. 1992). Species of *Catonotus* attach and guard eggs on the underside of flattened substrates (Page 1983; Page et al. 1992). Kentucky harbors 11 species in the subgenus (Burr and Warren 1986; Page 1983; Page et al. 1992). Many species, e.g., the fantail darter, *Etheostoma flabellare,* are widely distributed in the state, while others including the relict darter, *E. chienense,* are restricted in distribution (Biggins 1993; Warren et al. 1994).

The relict darter, *Etheostoma chienense* Page and Ceas, is a recently described species (Page et al. 1992) endemic to the Bayou du Chien drainage of western Kentucky (Biggins 1993; Webb and Sisk 1975; Warren et al. 1994); prior to 1994 little information was available regarding life-history traits (Piller and Burr n.d.; Warren et al. 1994).

Etheostoma chienense is restricted in terms of its range. Previous surveys of the Bayou du Chien drainage conducted by Webb and Sisk (1975) and by Warren et al. (1994) revealed that the species occurred at only nine sites and was known to spawn in only one tributary in the upper reaches of the drainage. As a result of its limited distribution, the relict darter was listed as federally endangered in 1993 (Biggins 1993). In addition to the species' restriction to a small watershed, two other factors including the lack of suitable spawning substrate and, at the time of listing, only one reported spawning reach also contributed to the federally endangered status (Warren et al. 1994).

Distributional studies of rare taxa are necessary when researchers attempt to formulate appropriate management decisions. Our study was undertaken to document the present distribution and to determine population estimates for *E. chienense.*

STUDY AREAS

The Bayou du Chien is a gravel, mud, cobble, and sand-bottomed Coastal Plain system that is a direct tributary of the Mississippi River. The entire watershed is privately owned and is used principally for agriculture. This drainage lacks the slabrocks characteristically used for spawning by most species of *Catonotus* (Warren et al. 1994) and, as a result, *E. chienense* is opportunistic in terms of egg deposition substrates and will deposit its eggs on the underside of almost any hard substrate (Piller and Burr n.d.).

The entire Bayou du Chien drainage served as the study area (Figure 1). It originates in southwestern Graves County and flows in a northward arc through Hickman and Fulton counties to its confluence with the Mississippi River near Hickman, Kentucky. It drains ca. 554 km^2, most of which is fertile farmland (Burr and Warren 1986).

Many of the common problems affecting the streams of eastern North America have

[1] Present address: Tulane University Museum of Natural History, Belle Chasse, LA 70037.

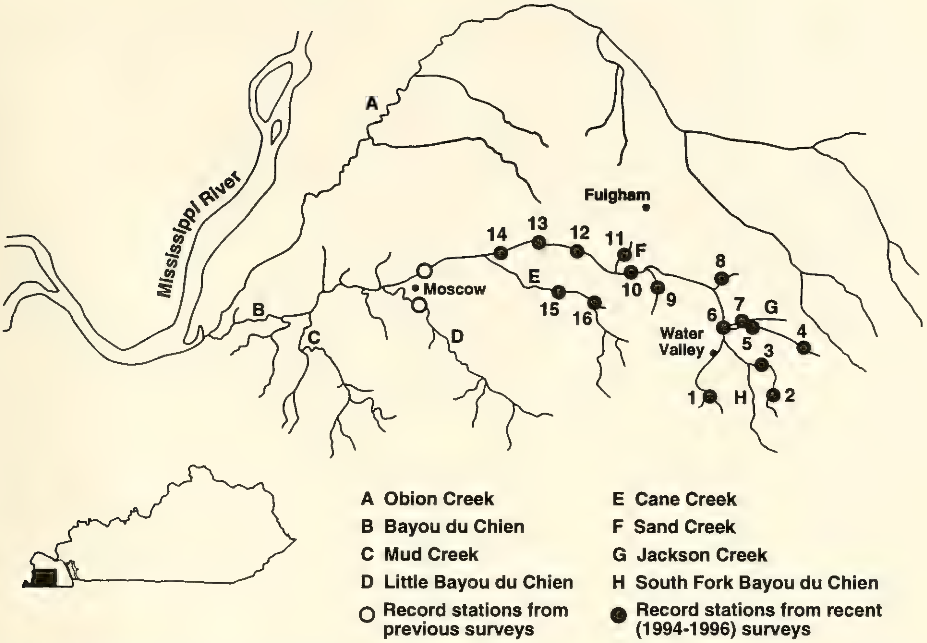

Figure 1. Distribution of *Etheostoma chienense,* Bayou du Chien drainage, Graves, Hickman, and Fulton counties, western Kentucky, 1994–1996. Numbers refer to localities of occurrence (see text).

also affected Bayou du Chien. Stream channelization has lead to a loss of appropriate or suitable habitat and change in stream flow patterns. All but the final 8–10 km of the system has been channelized (Webb and Sisk 1975). The Bayou du Chien, presumably once a free-flowing stream with numerous riffles, runs, and gently flowing pools, has been converted to a deep ditch with sluggish, turbid water. More importantly, many stream reaches in the drainage have had riparian vegetation completely removed. Such vegetation normally shades the stream, decreases silt load, and, most notably, provides spawning substrate for darters. Warren et al. (1994) believed that the lack of woody riparian vegetation and the low availability of suitable spawning substrates have adversely impacted relict darter populations.

METHODS

Monthly visits were made to Bayou du Chien and many of its tributaries in late summer and early fall 1994 and 1995 to assess distribution and population status of the relict darter. Collection localities were primarily sites sampled by Webb and Sisk (1975) and Warren et al. (1994), but several others within the drainage were sampled in an effort to discover new localities of occurrence. Because of the endangered status of the species, no specimens were vouchered from any new sites. Sampling was accomplished using standard minnow seines (Jenkins and Burkhead 1993) and dip nets, and all captured darters were measured to the nearest millimeter (SL) and then released. Length data were used to analyze population structure by way of length-frequency estimation.

In spring 1996 we obtained a population estimate for each site where *E. chienense* was captured. All estimates are based on 200 linear meter reaches (100 m along each stream bank). Areas in the middle reach of a stream were excluded because of the affinity of *E. chienense* for undercut banks and other near-bank cover (Piller and Burr n.d.). Several 10–20 m reaches were measured and sampled at each site. We attempted to capture darters within each section by "kicking" around in-stream objects and beneath undercut banks. A block net was used in small tributaries to help increase catch rate and avoid darter escape. After sampling several sections, we obtained a

Table 1. Sites surveyed in 1994–1996 in the Bayou du Chien drainage that produced *Etheostoma chienense* with habitat data, population estimates, and population status for each site of occurrence. Site numbers refer to numbered sites in Figure 1 and the text.

Locality	Suitable habitat (m/200 m)	Density (darters/m)	Darters (darters/ 200 m)	Population status	Riparian zone (m)
Site 1. Trib. of Bayou du Chien, Rt. 94/45	120	0.000	0	Rare	1–2
Site 2. South Fork Bayou du Chien, Kingston Rd.	20	0.100	2	Rare	1–2
Site 3. South Fork Bayou du Chien, Pea Ridge Rd.	80	0.100	8	Uncommon	0–1
Site 4. Bayou du Chien, 2422 Rd.	60	0.256	15	Common	1–2
Site 5. Bayou du Chien, Bard Rd.	10	0.100	1	Rare	0
Site 6. Bayou du Chien/Jackson Creek/South Fork BDC	88	0.200	2	Uncommon	1–2
Site 7. Jackson Creek, Lawrence Rd.	140	0.755	106	Abundant	4–6
Site 8. Bayou du Chien, Rt. 1283	140	0.430	60	Common	3–4
Site 9. Unnamed trib., Bayou du Chien, Rose Rd.	50	0.200	10	Uncommon	3–4
Site 10. Bayou du Chien, Rt. 307	130	0.500	65	Common	2–3
Site 11. Sand Creek, Rt. 307	100	0.000	0	Rare	2–3
Site 12. Bayou du Chien, Davis Rd.	130	0.375	49	Common	2–3
Site 13. Bayou du Chien, Howell Rd.	100	0.066	7	Uncommon	0–1
Site 14. Bayou du Chien, Rt. 51	100	0.230	23	Uncommon	2–3
Site 15. Cane Creek, Howell Rd.	40	0.500	20	Uncommon	0–1
Site 16. Cane Creek, Coolie Rd.	100	0.066	7	Rare	2–3

mean darter density for each site by averaging the results obtained from each 10–20 m section sampled. In addition, the amount of suitable habitat (i.e., undercut banks or instream cover) was also estimated for each 200 m study area. Population estimates were obtained by multiplying the mean darter density by the amount of suitable habitat at each site.

In addition to a population estimate for each site, we obtained a drainage-wide population estimate by averaging the results from the site-by-site analysis. The total linear stream meters inhabited were multiplied by the average amount of suitable habitat obtained in the areas where *E. chienense* was captured to arrive at the total amount of suitable habitat. The lower range of the population estimate was determined by multiplying the total amount of suitable habitat by the average darter density within the drainage. The resultant population estimate should be less than the actual number because not all darters were captured and because the relict darter probably inhabits additional stream kilometers. To determine an upper range, we used the greatest darter density and multiplied it by the total amount of suitable habitat.

The site-by-site population estimates were obtained from a one-time sampling effort, which may not accurately describe the population status of *E. chienense*. To account for the single- census bias, we used the following categories to classify the abundance of relict darters at each site over the 2-year sampling period: (1) Rare—species captured or vouchered only once or very infrequently; (2) Uncommon—captured semi-regularly, but usually only in small numbers; (3) Common—collected regularly and usually found in moderate to large numbers; and (4) Abundant—commonly collected in large numbers, one of the dominant species.

RESULTS

The relict darter was most commonly collected in the upper reaches of the drainage in both the mainstem of Bayou du Chien and many of its smaller tributaries. Sixteen of the 28 sites sampled or reconnoitered within the drainage produced *E. chienense* adults, juveniles, and/or nests (Figure 1)(Table 1). (See Piller [1996] for a complete listing of all sites sampled.) *Etheostoma chienense* presently inhabits a total of 94,200 linear meters of stream (47,100 m for each stream bank); population estimates suggest that the total drainage population is between 9533 and 31,293 individuals. Following is a summary of all known sites of occurrence of *E. chienense*. Each section gives the population estimates taken in spring 1996, the population abundance status at each site as observed over the 2-year sampling period, and a detailed habitat description of each locality of occurrence.

Site 1. Tributary to Bayou du Chien, near intersection of Rt. 45 and Rt. 94, 0.5 km s of Water Valley, Graves Co., rare. Two unguarded nests were found on 9 Apr 1994, and a single nest was discovered on the underside of a broken piece of concrete on 15 Apr 1995. Although it is evident that reproduction occurs at this site, it is likely that few individuals inhabit this locality. Habitat modification and degradation at this site are acute. Cultivated fields extend to the edge of the stream, and only a few scattered trees remain along the bank. The tributary has been channelized, and the stream flow velocity is low. The bottom substrate consists entirely of mud and silt. Return trips to collect additional specimens proved unsuccessful. It is possible that the spawning adults may have been waifs washed downstream during a flood. No darters were captured at this site in the 1996 survey; therefore we have a population estimate of zero individuals for this site.

Site 2. South Fork Bayou du Chien, Kingston Rd., Graves Co., rare. This site was sampled on 27 Aug 1994 and 11 Mar 1995 and failed to produce any *E. chienense*, but on 2 Apr 1996 a 66-mm male and a 46-mm female were captured beneath a small log anchored to the bank. Both were in breeding condition and were apparently ready to spawn. Additional sampling failed to produce other *E. chienense.* Suitable habitat and instream cover are limited. The substrate consists entirely of sand, and virtually no undercut bank habitat is available. We conservatively estimate 1 m of suitable habitat per 10 linear meters of stream. A narrow 1–2 m riparian zone exists, but trees are sporadic along the stream bank. From the low darter densities and the lack of suitable habitat, we estimate that two *E. chienense* inhabit the sample area.

Site 3. South Fork Bayou du Chien, Pea Ridge Rd., 2.4 km e of Water Valley, Graves Co., uncommon. This site was sampled by Webb and Sisk (1975) and Warren et al. (1994); both failed to capture any *E. chienense.* In our study, the site was sampled three times and initially produced two adults (71 and 62 mm SL) on 11 Mar 1996 that were collected ca. 40 m downstream from the bridge under a partially submerged railroad tie. Two other individuals (74 and 58 mm) were collected in a deep undercut bank in water 0.75–1 m deep. The riparian zone upstream from the bridge has been removed, and the stream bed has been channelized. Subsequent sampling trips produced only small numbers of individuals and no more nests. Downstream from the bridge are long stretches of sand raceways and numerous deep pools. Few undercut banks or spawning habitat are available and, although a narrow riparian zone remains, it consists largely of herbaceous vegetation. We estimate that eight *E. chienense* inhabit the 200 linear meters sampled.

Site 4. Bayou du Chien, 2422 Rd., 3.2 km ne of Water Valley, Graves Co., common. This locality is one of the uppermost sites surveyed in the main channel of Bayou du Chien. The stream averages 2–3 m in width; the substrate consists entirely of sand and gravel. The majority of suitable habitat lies upstream from the bridge. A 1–2 m wide woody riparian zone is present on both sides. The downstream reach has been significantly modified. Cultivated fields extend to the stream's edge, and woody bankside vegetation has been almost completely removed. We conservatively estimate that 15 *E. chienense* occupy the sample area.

Site 5. Bayou du Chien, Bard Rd., Graves Co., rare. This site averages ca. 1–2 m in width, and no woody riparian zone is present (Figure 2A). The stream has been dredged and straightened and little or no undercut bank habitat is available. The only instream cover is a few scattered pieces of limestone rip-rap used for bank stabilization. This is the most anthropogenically modified site sampled in the drainage. The amount of suitable habitat and darter density is extremely low. We estimate that one darter occupies the 200 linear m reach sampled.

Site 6. Bayou du Chien, Jackson Creek, and South Fork Bayou du Chien, Rt. 45, Graves Co., uncommon. These localities were lumped into a single site because of their geographic proximity. All three sites merge within a 100 m reach. This site maintains water year-round due to several coldwater springs feeding South Fork Bayou du Chien. The site was eutrophic with many filamentous green algae present along the stream bottom, even during mid April. Eutrophication is likely a consequence of the extremely small riparian zone

Figure 2. Contrast in localities where *Etheostoma chienense* was collected during the 1994–1996 survey. (A) site 5, a highly modified reach, Bayou du Chien, Bard Rd., Graves Co., KY; (B) Site 7, ideal habitat, Jackson Creek, Lawrence Rd., KY.

and the agricultural field that borders the south side of the stream. The north side has an adequate riparian zone ca. 3–4 m wide. On 16 Apr 1995 this site yielded a single male guarding a nest attached to the underside of a rubber tire. No other darters were captured during the study. We estimate that two darters occupy the sample area.

Site 7. Jackson Creek, northeast of Water Valley on Lawrence Rd. (formerly Roy Lawrence Dr.), Graves Co., abundant. Prior to 1994 Jackson Creek was the only stream in the Bayou du Chien drainage known to harbor a spawning population of *E. chienense* (Biggins 1993; Warren et al. 1994). One of the uppermost sites surveyed in the drainage, it is the type locality of *E. chienense* (Page et al. 1992). Jackson Creek is a first-order tributary that averages 1–3 m in width. Substrate consists of sand and gravel; although no slabrocks are present, a few areas contain small concentrations of cobble (64–256 mm). Downstream from the bridge, there is an extensive tree canopy covering the stream and a substantial amount of undercut bank habitat. The riparian zone, consisting of deciduous trees and herbaceous vegetation, extends 4–6 m in width on both sides (Figure 2B). Above the bridge, a cattle pasture borders both sides of the stream, and although a few large trees are still present along the surrounding fenceline, the riparian zone has been significantly reduced. A substantial amount of woody debris existing in the riparian zone (above and below the bridge) is deposited into the stream. This in turn provides a surplus of spawning substrate and cover for darters and other aquatic species. Jackson Creek has been relatively unaffected by anthropogenic modifications; the pristine nature of the stream undoubtedly contributes to the healthy population at this site. Extrapolating, we estimate that 106 darters occupy the site. This population is the largest in the drainage and is one of the primary areas of recruitment.

Site 8. Bayou du Chien, Rt. 1283, 4.5 km n of Water Valley, Hickman/Graves Co., common. This site has been subject to a variety of human modifications. Above the bridge, the stream is ca. 4–6 m wide, and a narrow woody riparian zone exists on both sides of the stream. There are ca. 20 m of suitable habitat immediately upstream from the bridge, but the remaining reach has been channelized and little suitable habitat is present. Silt-covered substrates, sluggish flow, and lack of heterogeneity undoubtedly contribute to low densities. Although the area below the bridge has been partially channelized, the stream flows more freely, has a higher velocity, and harbors a greater density of *E. chienense.* Sand is the dominant substrate below the bridge, but there is a small area (100 m^2) near the bridge that has many cobble-sized rocks available for spawning. The woody riparian zone has been significantly reduced, but the remaining vegetation extends about 1–2 m on either side of the stream. We estimate that 60 individuals occupy the sample area, which stretches from ca. 25 m above the bridge to 75 m below.

Site 9. Unnamed tributary, Bayou du Chien, Rose Rd., 6.7 km se of Fulgham, Hickman Co., uncommon. This site failed to yield specimens in both of the previous surveys, but several adults and nests were discovered on 31 Mar 1996. There is an abundance of woody material available for nesting, but little undercut bank habitat exists. Flow is extremely low, and it is likely that this small tributary dries completely in the late summer and early fall. Several females also were collected on 9 Apr 1996, but no other nests were discovered. The population estimate for this site is 10 individuals.

Site 10. Bayou du Chien, Rt. 307, 4.5 km s of Fulgham, Hickman Co., common. The Rt. 307 site yielded darters during both of the previous surveys, and *E. chienense* was relatively common in the present study. A multitude of spawning habitat and cover is available including tree roots extending into the water, logs and sticks deposited from the overhanging tree canopy (2–3 m riparian zone), and deep undercut banks. This reach of Bayou du Chien has been partially straightened and widened. We estimate that 65 darters occupy the sample area, which stretches from 50 m above the bridge to 50 m below.

Site 11. Sand Creek, Rt. 307, 4.0 km s of Fulgham, Hickman Co., rare. This small stream can be classified as ephemeral or intermittent. The stream commonly lacks water or dries to isolated pools in summer and early fall. Sand Creek was sampled nine times during the study. Several adults were captured in 1994, but few individuals since. Four nests

were found in the 3- year study. No individuals were found during the Warren et al. (1994) study, but Webb and Sisk (1975) reported captures, although vouchers remain unavailable. The riparian zone averages ca. 1–2 m in width, and an ample amount of undercut bank habitat is available. Although it was shown that spawning does occur, it is likely that many *E. chienense* larvae become trapped in isolated pools in times of low water. No *E. chienense* were captured in 1996, and few others were captured in previous visits. We estimate that zero darters occupy this site. Low water levels and the intermittent nature of the stream seem to be the main reasons that few individuals or nests have been discovered at this locality.

Site 12. Bayou du Chien, Davis Rd., 4.8 km sw of Fulgham, Hickman Co., common. The Davis Rd. site yielded three specimens for Webb and Sisk (1975) and Warren et al. (1994). On 8 Aug 1995, 15 individuals were collected in fewer than 30 minutes, while on 23 Mar 1996 only four individuals were collected in the same time frame. Several nests were photographed in 1995 and 1996. Reaches above and below the bridge are similar. An ample woody riparian zone remains along the stream's edge, but channelization is evident. A substantial amount of spawning habitat is present, and many undercut banks exist. For the sample area, which extends from immediately below the bridge to 100 m downstream, we estimate that 60 darters inhabit the reach.

Site 13. Bayou du Chien, Howell Rd., Hickman Co., uncommon. This site has a mainstem character averaging 7–8 m wide with a strong flow. There are no alternating stretches of riffle-pool habitats, and undercut bank microhabitat is limited. The site failed to yield specimens, but two unguarded nests attached to small sticks were found on 2 May 1996. Below the bridge the south stream bank almost completely lacks woody vegetation with only a few scattered trees present along the bank. On the north side a riparian zone greater than 5–6 m extends along the bank. Above the bridge, a buffer zone 3–4 m wide borders both sides of the stream. Although a suitable riparian zone is present at this site, the channel has been straightened and ditched. No adults were ever captured, but two nests were discovered in the area sampled. We estimate that two darters occupy the area.

Site 14. Bayou du Chien, Rt. 51, 0.8 km se Clinton, Hickman Co., uncommon. Prior to our study, the farthest downstream localities of occurrence were Bayou du Chien, 6.4 km n Cayce, Hwy. 239, Fulton Co., and Bayou du Chien, 0.8 km n of Moscow, Hickman Co. Additional sampling efforts at these localities proved unsuccessful. Bayou du Chien, Rt. 51, is presently the farthest downstream site of occurrence. This new locality was first discovered on 27 Aug 1995. Five individuals (28–45 mm) were captured near the bridge. Subsequent collections also have yielded specimens but always in low numbers. Little spawning habitat is available. Undercut banks are scattered, and some woody material has been deposited into the stream from the remaining woody vegetation. Upstream from the bridge, the riparian zone remains intact, but the stream channel has been ditched and straightened. The sampled area stretches 50 m above and below the bridge. We estimate that 23 darters occupy the area.

Site 15. Cane Creek, Howell Rd., uncommon. Two nests were found in 1994, a single nest was discovered on 31 Mar 1995, and several others were found in 1996. The area beneath the bridge and immediately upstream contained the only suitable habitat or cover within 200 m of the bridge. The spawning habitat consisted of several pieces of limestone rip-rap and small rocks. The area downstream has an extremely low flow rate and little undercut bank habitat. Riparian buffer zones extend 1–2 m to either side, and siltation is extremely high. Several silt-tolerant species were collected downstream including *Ameiurus natalis* and *Lepomis cyanellus*. The area upstream lacks a riparian zone; and tilled fields extend up to the stream's edge. The population estimate for this site may be misleading, because all suitable habitat occurs immediately below the bridge within a 5-6 m linear reach. We estimate that 20 darters occupy the sample area, most occurring in the vicinity of the limestone rip-rap.

Site 16. Cane Creek, Coolie Rd., rare. This site was sampled three times and failed to yield any adult *E. chienense.* Two nests attached to the underside of a large wooden board were discovered on 2 May 1996, but no

males were guarding the eggs at the time of discovery. This site has been moderately developed. A small 2–3 m buffer zone borders both sides of the creek. The creek averages 2–3 m wide and is fairly shallow but probably maintains flow year round. Much woody debris is scattered throughout the stream, but little undercut bank habitat is present. Because no darters were ever captured and only two unguarded nests were discovered, we estimate that two darters occupy the site.

Length–Frequency Estimation

Length–frequency estimates of all individuals captured from fall 1994 to spring 1996 revealed four age classes (Figure 3A). Separate length-frequency estimates were then determined for males (Figure 3B) and females (Figure 3C) from spring 1995 and 1996. Males were ca. 40 mm SL by age one and between 52 and 62 mm SL by age two. Age-three males ranged from ca. 63 to 76 mm SL. On the other hand, females were slightly smaller than males at each age class. Females were almost 35 mm SL by age one and ranged from 47 to 54 mm SL by age two. Age-three females were 55 to 68 mm SL.

DISCUSSION

Our results demonstrate that the distribution and abundance of *E. chienense* are both a function of the availability of quality habitat and the amount of suitable spawning substrata. The most viable populations were found in reaches having gently flowing water, abundant undercut bank habitat, low silt load, and a suitable quantity of spawning substrata or instream cover. Adults occurred almost exclusively in reaches with appropriate cover and spawning substrata and were absent or in low abundance at sites that lacked these features.

It is difficult to ascribe aquatic-habitat degradation to one or even two sources, but channelization and the removal of riparian vegetation are two factors that have reduced habitat heterogeneity in streams of the midwestern and southeastern United States (Karr and Schlosser 1977; Schlosser 1991; Warren and Burr 1994; Williams et al. 1989). Channelization is a common and biologically controversial practice aimed primarily at controlling flooding and increasing drainage rate of agricultural land. Stream channelization has severely impacted Bayou du Chien by changing stream flow patterns, reducing in-stream flows, and decreasing aquatic habitat complexity.

Historically, Bayou du Chien was presumably a free-flowing stream with alternating areas of riffles, runs, and pools. Although a few of these reaches remain, much of the stream has been converted to a deep ditch with uniform depth, velocity, and substrate. In times of high water or flooding, velocity rates are at their most extreme through channelized reaches of the stream. Straightening of the stream is aimed at increasing the drainage, but it also destroys and removes much of the instream cover. Many aquatic organisms cannot withstand increased flow rate and often seek alternative shelter during floods (Brookes 1988; Hynes 1970). Furthermore, channelized sections of stream often have little or no flow when water levels are below normal. Many aquatic organisms, including darters, prosper in flowing waters and cannot withstand stagnant or low oxygenated waters.

In addition, the removal of streamside vegetation, a common practice associated with stream channelization, is executed to increase the amount of tillable agricultural land. Streamside vegetation is critical in maintaining water quality. First, the tree canopy normally shades the stream, thus helping to maintain normal water temperatures (Hansen 1971; Karr and Gorman 1975). Second, rooted bankside vegetation assists in reducing bank erosion and stream turbidity by decreasing soil loss (Emerson 1971; Hansen 1971). Finally, woody vegetation provides allochthonous input into the stream and, most importantly, provides spawning substrate and cover for darters and other aquatic organisms.

The major impacts of anthropogenic modifications on the North American ichthyofauna have been well documented. Burr and Warren (1986) noted that, in Kentucky, stream channelization and the concomitant removal of woody vegetation have most negatively affected streams in the lowland regions of the lower Green River and Coastal Plain, including Bayou du Chien. Several other studies, including those of Congdon (1971), Etnier (1972), and Trautman and Gartman (1974), have documented the decrease of fish and invertebrate biomass following stream channelization.

Although no pre-modification data are avail-

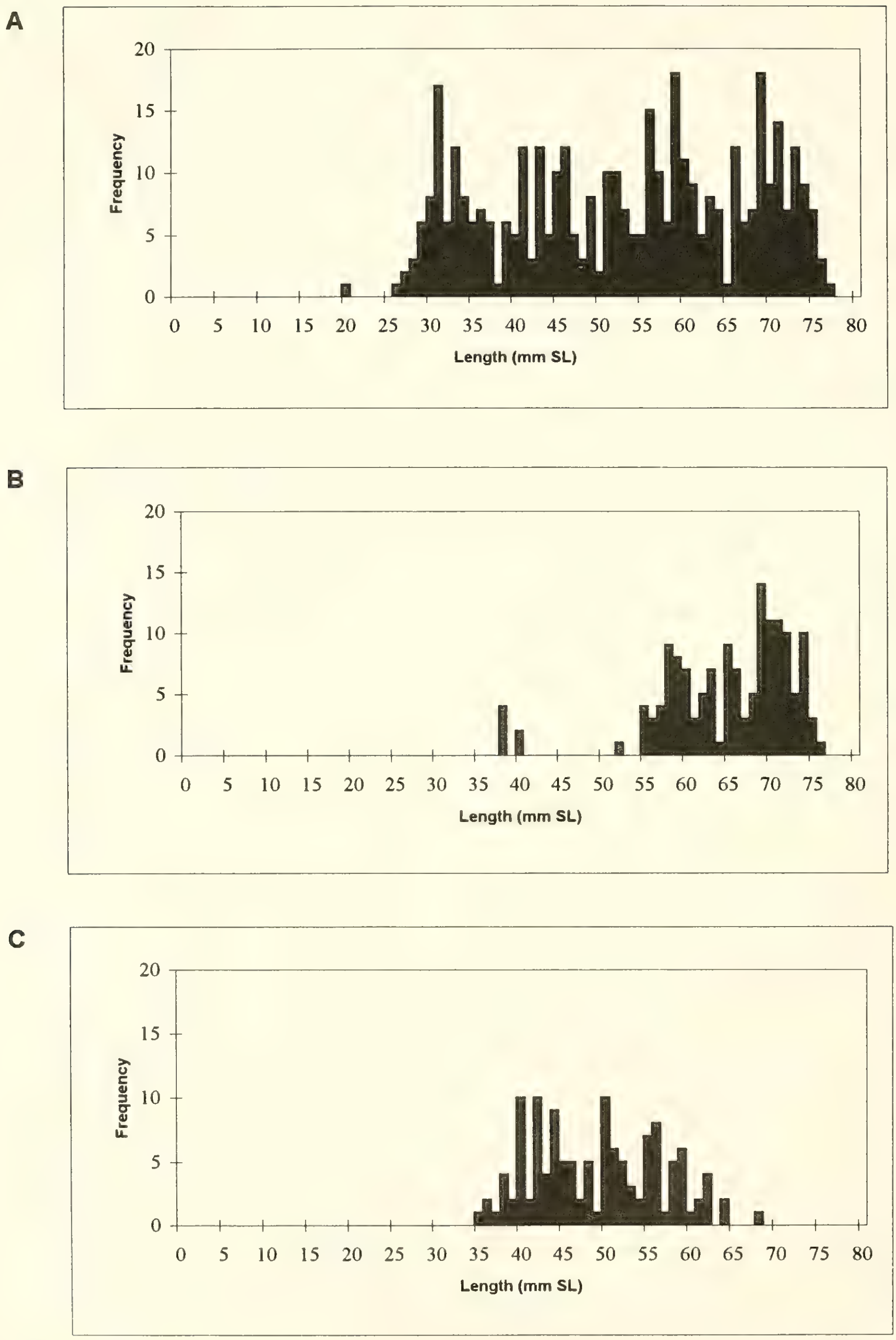

Figure 3. Length–frequency graphs of *Etheostoma chienense* based on (A) all individuals captured 1994–1996, (B) males spring of 1995 and 1996, and (C) females spring 1995 and 1996 from the Bayou du Chien drainage, western Kentucky.

able for comparison, several reaches of stream within Bayou du Chien have been channelized and deforested to different degrees, thus allowing comparisons within the drainage. *Etheostoma chienense* is abundant at only one site in the drainage, Jackson Creek, an unchannelized stream with a wide (4–6 m) riparian zone. A plethora of woody debris at this site provides an abundance of spawning substrata, and consequently Jackson Creek harbors the most viable population of *E. chienense.* The species is considered common at four additional localities. These sites have been moderately modified but still have adequate quantities of spawning materials and instream cover. At 11 of the remaining sample sites the species is rare or uncommon. Stream reaches such as those at South Fork Bayou du Chien, Pea Ridge Rd. (Site 3), and Bayou du Chien, Bard Rd (Site 5) have been radically modified and lack suitable riparian zones, and therefore contain low numbers of *E. chienense.*

Welsch (1992) provided minimum requirements for the reforestation of open lands and for the management of existing streamside buffer zones for the purpose of sediment removal, input of organic material into the stream, and maintenance of suitable water temperatures. According to these requirements, streamside buffer zones should consist of three distinct zones. Zone 1, nearest the streambank, should be ca. 5 m in width and left unmanaged. It should consist of a mix of native riparian trees and shrubs that can provide organic input into the stream in the form of leaf fall, large woody debris, and detritus. Zone 2 also should consist of native trees and shrubs but should have an average width of 20 m. The purpose of zone 2 is for filtration, denitrification, and sediment and nutrient removal from runoff. Zone 2, known as the managed forest zone, should have trees and shrubs periodically harvested to help maintain consistent vegetation growth. The runoff control zone (Zone 3) should be at the outward edge of zone 2 and average 6 m in width. The vegetation should consist of grasses and shrubs that need to be periodically mowed or grazed to help maintain growth. As mentioned before, the Bayou du Chien watershed is used presently for tillable agriculture; because of this, most of the streamside vegetation has been removed. Most sample sites on Bayou du Chien have a buffer zone of only 2–3 m rather than the 30 m proposed by Welsch (1992). An increase in the riparian zone of only 10 additional meters could positively benefit the *E. chienense* population.

The results of our length-frequency estimation indicate that the age groupings of *E. chienense* are similar to those reported for two other species of *Catonotus, E. squamiceps* (Page 1974) and *E. olivaceum* (Page 1980). Although age groupings here are comparable to what has been previously reported, age determination by length-frequency estimation is often unreliable (Jearld 1983). Without large sample sizes (500+ individuals) it is difficult to delineate age-classes because of overlapping groups among year classes. The low sample sizes in our study weaken the reliability of the age-classes.

STATUS, THREATS, AND RECOMMENDATIONS

In our 2-year study, seven additional sites of occurrence of *E. chienense* were discovered; it is likely that other, intervening areas not sampled also harbor viable populations. Historic localities, including two sites near Moscow, Kentucky, still remain void of relict darters. Collections by Webb and Sisk in the 1970s are the only vouchered specimens this far downstream; the species seems to be extirpated from these localities. Because the habitat is extremely sluggish and swamplike, the occurrence of *E. chienense* downstream of the Bayou du Chien, Rt. 239 bridge is extremely unlikely.

At the time of the Warren et al. (1994) survey, conducted in the fall, many of the small tributaries including Sand Creek, Rt. 307 and Cane Creek, Coolie Rd were totally dry or comprised of only isolated pools. Although several of these localities produced individuals during this study, it is likely that these intermittent streams contribute little to recruitment. In periods of low rainfall, nests may become desiccated because of low water levels, or young-of-the-year may become trapped in isolated pools and become subject to predation by birds or other organisms.

Etheostoma chienense is presently maintaining an effective population size; the potential for downlisting from federally endangered to federally threatened is conceivable in the fu-

ture. Several factors relevant to retention of the species endangered status include the following: (1) two sites that yielded specimens for Webb and Sisk (1975), Bayou du Chien, Hwy. 239 and Little Bayou du Chien, Hwy. 239 (Figure 1), failed to produce any specimens in our study; (2) range restriction of the species to only the upper reaches of the Bayou du Chien drainage; (3) the continuing effects of natural flooding and drought at several points along the stream, including drying of small tributaries during times of low flow; (4) evidence of pesticide and sediment runoff; (5) potential for heavy predation of larval *E. chienense* in the primary nesting areas (Piller 1996); (6) potential for further habitat alteration (i.e., dredging, snag removal, channelization, reduction of buffer zones); and, most importantly, (7) the lack of knowledge regarding the degree of recruitment of individuals into the population. No larval *E. chienense* were discovered in our study, and only a few juveniles were captured in late spring and early summer. After determining the habitat of larval *E. chienense* and the degree of recruitment into the existing population, an informed decision regarding endangered or threatened status should be made.

Etheostoma chienense has persisted in spite of various threats, but it cannot be assumed that its viability will remain indefinitely. A single toxic chemical spill into Jackson Creek or an extremely dry spring and summer could have devastating effects on population numbers. We recommend that the following steps be implemented and that *E. chienense* be monitored for several years.

1. Known sites of occurrence should be sampled periodically to determine trends in distribution and population abundance.
2. Habitat preferences of juvenile and larval *E. chienense* should be determined. Although we have documentation that nesting occurs at several localities in the upper reaches of the drainage, the biology of larvae is unknown, and consequently recruitment estimates are lacking.
3. Habitat quality should be maintained throughout the drainage. The proper authorities (U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Kentucky Department of Fish and Wildlife Resources) should attempt to closely monitor the entire drainage and limit the number of permits granted to snag, channelize, or modify the existing watershed.
4. In the future, voluntary planting of woody riparian vegetation should be done along stream banks to help decrease sedimentation, to provide suitable habitat for terrestrial organisms, and, most importantly, to provide spawning substrata for relict darters should be strongly suggested to private landowners. The specifications proposed by Welsch (1992) are perhaps unrealistic for the Bayou du Chien. The entire watershed is in private ownership, with agriculture being the primary use of the watershed. The creation of large buffer zones, even an increase of 10 m of woody streamside vegetation, would almost certainly be beneficial to the species.
5. Spawning substrate (i.e., ceramic tiles) should be added annually. As shown previously (Piller and Burr n.d.), the artificial spawning substrate provides an effective management tool that increases nest productivity and presumably enhances survivorship and recruitment. Seeding stream reaches throughout the upper portion of the drainage for several consecutive years may significantly increase or at least maintain current population numbers.

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The Morehead Radio Telescope, Morehead State University, Morehead, Kentucky: Design and Fabrication of a Research Instrument for Undergraduate Faculty and Student Research in Radio Frequency Astrophysics

Benjamin Malphrus, Eric Thomas, Michael Combs, Brian Lewis, Bob Ratliff, Brian Roberts, Chad Pulliam, Jennifer Carter, John Pelfrey, Dara Preece, and Viju Hullur

Morehead Astrophysical Observatory, Morehead State University, Morehead, Kentucky 40351

Russell Brengelman, David Cutts, and Charles Whidden

Department of Physical Sciences, Morehead State University, Morehead, Kentucky 40351

Rodney Stanley, Robert Hayes, and William Grise

Department of Industrial Education and Technology, Morehead State University, Morehead, Kentucky 40351

Drew Henderson

Information Technology, Morehead State University, Morehead, Kentucky 40351

Daniel Puckett

ACE Engineering, Morehead, Kentucky 40351

and

Jeff Kruth

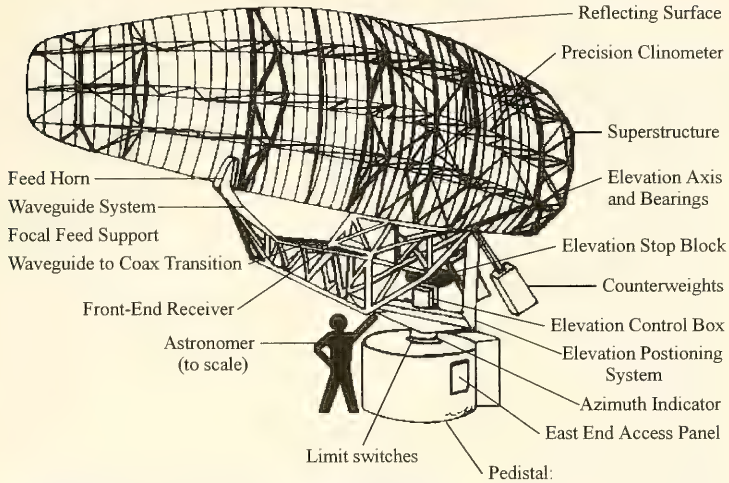
Kruth-Microwave Electronics, Hanover, Maryland 21076

ABSTRACT

Faculty and students of the Departments of Physical Sciences and Industrial Education and Technology at Morehead State University have designed and assembled the Morehead Radio Telescope (MRT) to provide a research instrument for undergraduate astronomy and physics students and an active laboratory for physics, engineering, and computer science undergraduates and faculty. The telescope functions as a research and educational instrument for undergraduate students, faculty, and science teachers throughout Kentucky. The goals of the MRT program are to enhance curricula in physics, physical science, electronics, and science education programs by serving to provide (1) a research instrument for investigations in astronomy and astrophysics; (2) an active laboratory in astronomy, physics, electrical engineering, and computer science; and (3) a research instrument and laboratory for science teacher education and in-service programs. The telescope incorporates a modular design in which components may be easily removed for use in laboratory investigations and in student research and design projects. The performance characteristics of the telescope allow a varied and in-depth scientific program. The sensitivity and versatility of the telescope design facilitate the investigation of a wide variety of astrophysically interesting phenomena. The MRT provides hands-on experience in research and instrumentation technology in a cutting-edge science, one that is in the midst of scientific revolution.

INTRODUCTION

The design of the Morehead Radio Telescope (MRT), Morehead State University (MSU), Morehead, Kentucky, provides an instrument capable of supporting scientific research in observational astrophysics at radio frequencies. The design and fabrication of the basic MRT systems are complete; first light was achieved on 12 Oct 1996. An overview of the MRT instrumentation, detailed description of major subsystems (antenna, alt-azimuth drive and control systems, optoisolator circuitry, receiver systems, and controlling computer and interface), theoretical performance characteristics, intended scientific programs, and project significance is provided herein.



Dimensions and Motion	
Reflecting Surface:	44 ft * 11 ft (13.42 m * 3.35 m)
Total Surface Area:	409 ft squared (38m squared)
Focal Distance:	3.50 m
Moving Weight:	1,155 kg
Total Weight:	4,527 kg
Positioner:	Automated Az.-alt. system
Elevation Range:	0 Degrees to 90 Degrees
Azimuth Range:	0 Degrees to 360 Degrees
Slew Rates:	20 min/360Degrees Az. 10 min/ 90 Degrees El.
Data Collection:	Automated tracking and transit modes

Figure 1. Morehead Radio Telescope (MRT), Morehead State University, Morehead, Kentucky. Morehead Radio Telescope systems and subassemblies. Major systems and subassemblies are identified in the diagram as well as dimensions of the instrument and positioning characteristics.

MRT INSTRUMENTATION

The basic design of the MRT includes a wire-mesh parabolic reflecting antenna, alt-azimuth tracking positioner control and drive systems, receiver and signal processing system, controlling computer with an interface device, and supporting electronics and hardware (Figure 1). The system is designed around a total power receiver that converts radiation from space concentrated by the antenna system to an electrical signal, which is amplified, modified, and interpreted. The MRT system is controlled by a Macintosh IIsi controlling computer and utilizes a National Instruments Lab NB interface board, optical isolation system, and robotic drive and control systems developed by MSU faculty and students. The controlling computer positions the telescope, instructs it in robotic tracking of cosmic sources, and controls data collection and storage. The data from a particular experiment are then transferred via ftp to a Sun Sparcstation for imaging and analysis (Malphrus et al. 1992).

Antenna

The MRT employs a high-gain, 40-foot antenna designed for L-Band operation. A surplused Army NIKE-Hercules ANS-17 radar antenna was obtained and modified for radio astronomy applications. The antenna was selected because of its large aperture, excellent aperture efficiency (afforded by its innovative offset feed design), and low cost. The original system included a parabolic reflector, antenna feed horn, waveguide system, and azimuth positioning system. The unmodified positioning system provided azimuth coverage of 360 de-

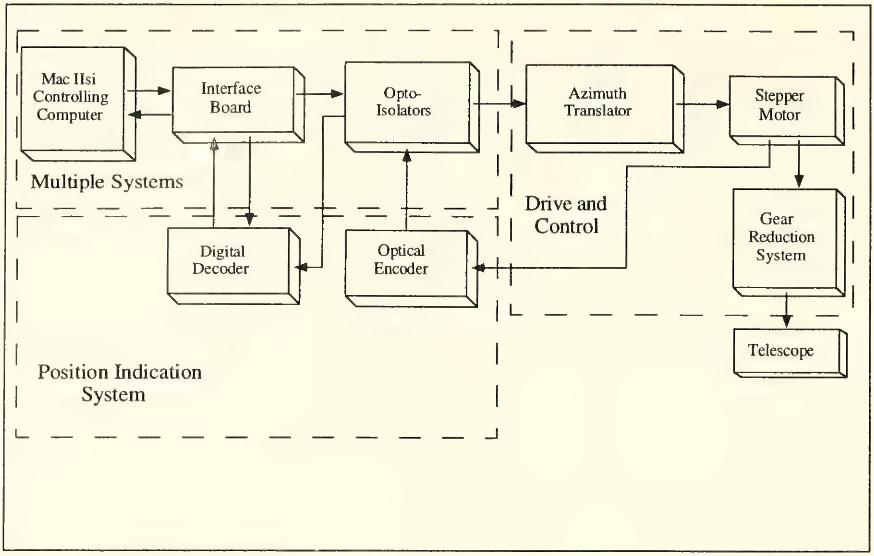


Figure 2. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT azimuth control and drive system. This schematic diagram outlines drive and control system as well as the indication system designed to position the telescope in azimuth.

grees at a continuous antenna rotation speed of six revolutions per minute.

The main purpose of the antenna system is to track objects in space and to collect and concentrate radio signals from space. These radio signals are then focused by the reflector to a single focal point on the antenna horn where a waveguide system transmits the electromagnetic wave to a terminus at which the front-end receiver is located. A probe inserted into the waveguide to coax transition converts the electric field of the radio wave to an electrical signal via electromagnetic induction. The electrical signal is then amplified and conditioned by the receiver front-end, which then sends the data to the back-end receiver and controlling computer to be further conditioned and analyzed.

Azimuth and Elevation Drive and Control Systems

Positioning the telescope is accomplished by alt-azimuth and elevation drive and control systems designed and built by MSU faculty and students and Automation Concepts and Engineering (ACE). The systems utilize a common controlling computer and interface board, independent electromechanical drive-train, and positioning control systems. A block diagram of the azimuth drive and control systems is provided in Figure 2. The azimuth drive system incorporates a translator, stepper motor, and gearing system that drives a 6-foot diameter bull gear inside a rotating turret to which the telescope superstructure, antenna, and feed support system (the moving components of the telescope) are attached. The elevation drive system incorporates a more radical rod-and-reel type design. A fixed axle is positioned at the center of gravity of the moving component of the telescope. The axle is affixed to rotating couplers located on top of a supporting elevation positioning assembly. Motion in elevation is accomplished by controlling the motion about this axle with a rod-and-reel assembly positioned at the base. Cables attached to pick points on the focal feed support structure are reeled in and out around a rod driven by the elevation control assembly. The elevation control assembly consists of a translator, stepper motor, gearing, and coupling system that control the rotation of the rod, motion of the cables, and ultimately motion of the telescope about the elevation axis (Figure 3) (Malphrus 1996).

Multiple-Use Systems

Macintosh IIsi controlling computer. The Macintosh controlling computer is a standard

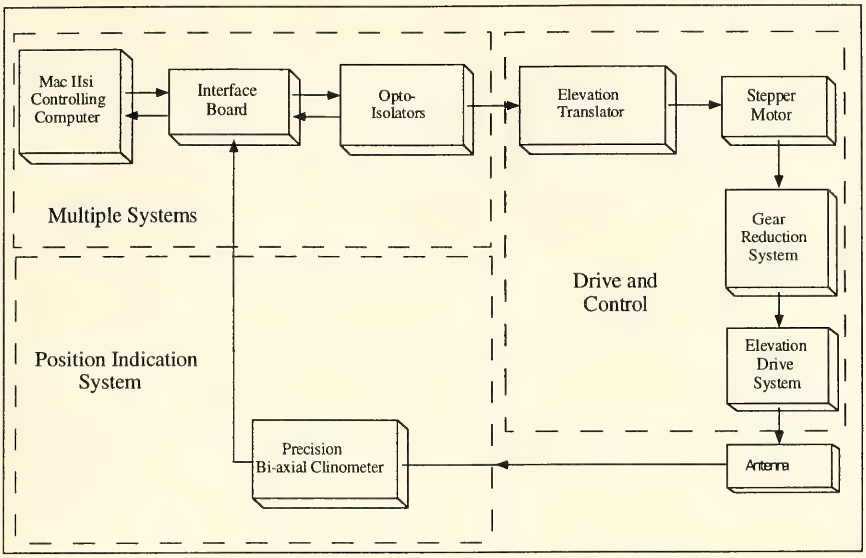


Figure 3. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT elevation control and drive system. This schematic diagram outlines drive and control system as well as the indication system designed to position the telescope in elevation.

microcomputer that utilizes a Motorola 6040 microprocessor and has 16 MB of RAM and 1 GB of hard disk memory with a mathematics co-processor. A multi-function analog, digital, and timing I/O (input/output) board is installed in the computer. It contains a 12-bit, successive approximation A/D converter with eight analog inputs, two 12-bit D/A converters with voltage outputs, 24 lines of transistor-transistor logic compatible I/O, and three counter/timer channels for timing I/O. The multifunction interface board is controlled by LabVIEW, a software system featuring interactive graphics, a state-of-the-art user interface, and a powerful graphical programming language "G." This software is used (1) to send the input pulses to both the azimuth and elevation translators; (2) to move the telescope; (3) to analyze the data collected from the optical encoder and clinometer; and (4) to collect data from the receiver system. The signal path from the controlling computer to the drive and positioning systems is outlined in Figure 4.

Interface board. A National Instruments LAB-NB Interface Board is used to interface the computer with the electromechanical hardware. It is used primarily to interface the computer's I/O board with the hard wiring of the telescope's drive, control, and receiver systems.

Optoisolators. The optoisolators are electronic circuits designed and built by MSU students and faculty and ACE Engineering. The purpose of the optoisolators is to isolate high voltage components of the system from low voltage components of the system. There are two types of optoisolators: transmitters, which transmit the signals from low voltage circuits, and receivers, which receive the signals from high voltage circuits. A system of optoisolators is incorporated into the drive and control circuitry for total optical isolation. A schematic diagram of the MRT optoisolator system as wired is given in Figure 5.

Drive and Control Systems

Azimuth translator. The azimuth translator is a self-contained unit incorporating the power circuits and logic elements needed for bi-directional control of a stepper motor. The azimuth translator was designed and built by MSU students in cooperation with ACE Engineering. It can be triggered by pulses from an internal oscillator or from an external pulse source and will drive the motor at a rate of up to 1,000 steps per second. The unit can be

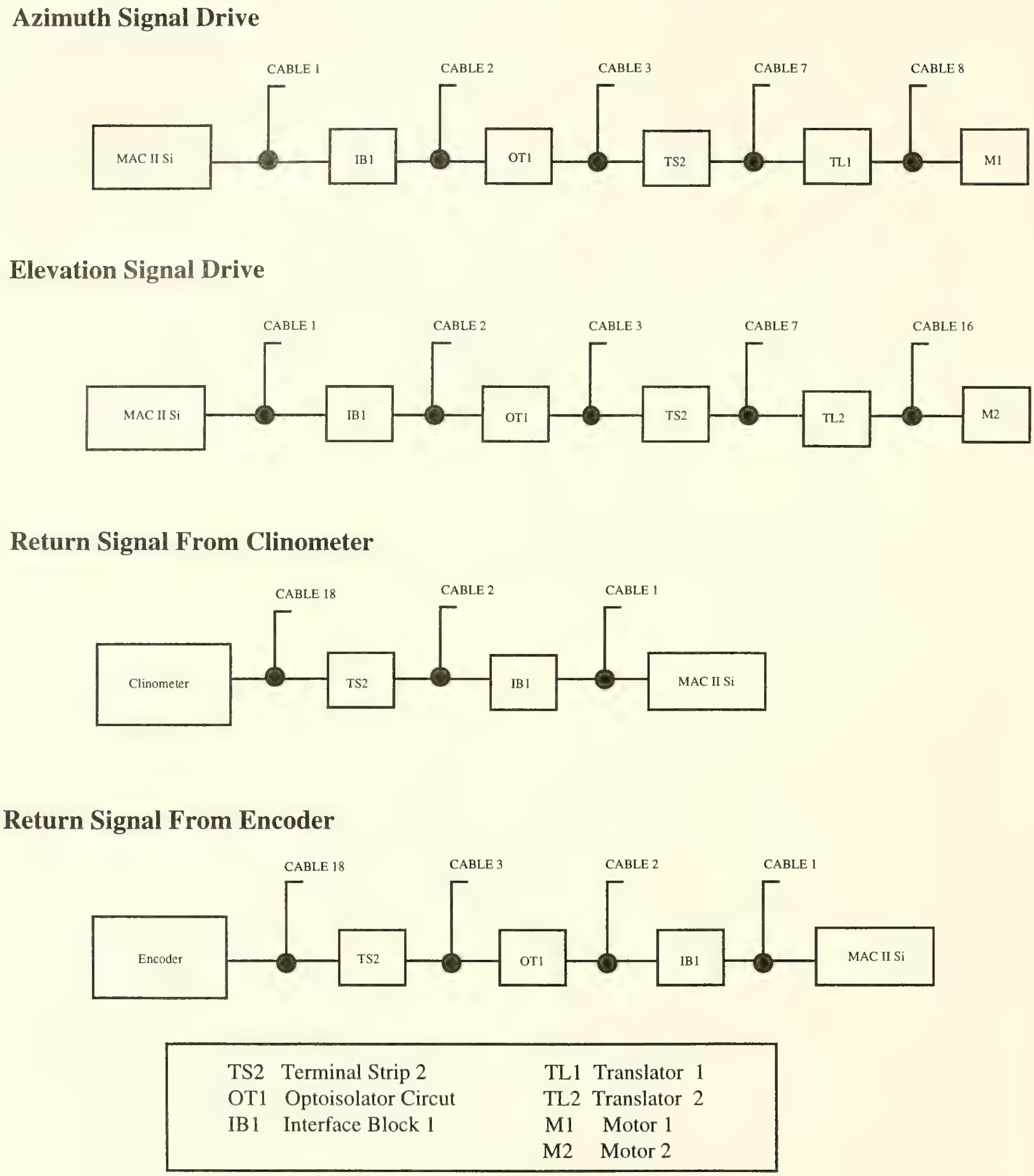


Figure 4. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. Telescope drive and positioning systems signal path. This schematic diagram summarizes the signal path for the azimuth drive signal, the elevation drive signal, the return signal from the elevation clinometer, and the return signal from the azimuth encoder.

operated in ambient temperatures from 0°C to +40°C. The azimuth translator is used to control the azimuth stepper motor; a similar elevation translator is used to control the elevation stepper motor.

Stepper motors. The SLO-SYN stepper motors operate as phase-switched DC motors. The motor shaft advances 200 steps per revolution (1.8° per step) when a four-step input sequence (full-step mode) is used and 400 steps per revolution (0.9° per step) when an eight-step input sequence is used. Logic devices are normally used for switching the speeds. Counterclockwise rotation is obtained

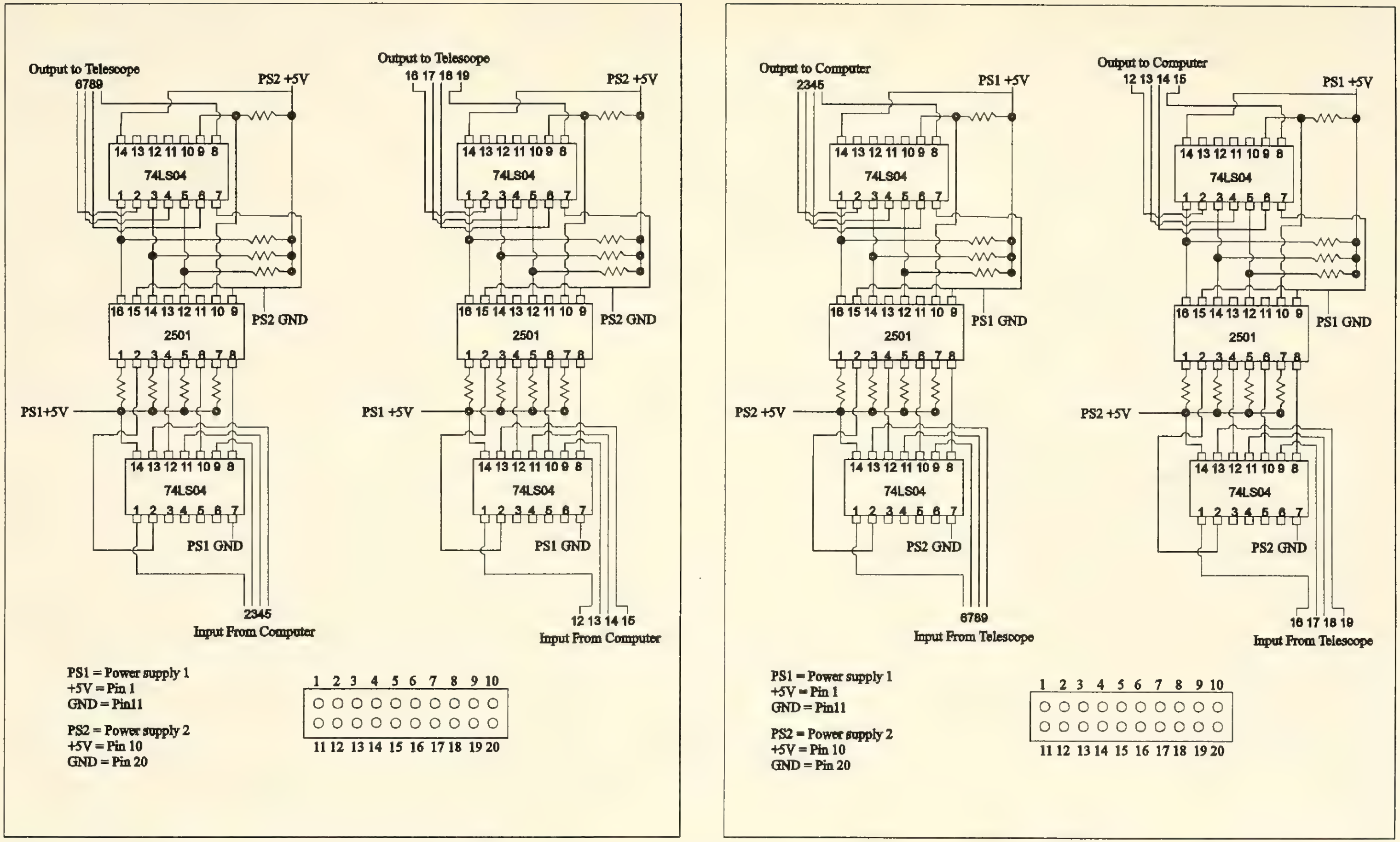


Figure 5. Morehead Radio Telescope (MRT), Morehead State University, Morehead, Kentucky. Optoisolator circuit. The optoisolator circuit is designed to optically isolate the low-voltage back-end receiver and spectrometer from the high voltage front-end receiver to protect the back-end against undesirable power surges.

by reversing the order of the switching steps of the clockwise rotation.

Gear reduction system. The gear reduction system utilizes precision-built parallel shaft speed reducers specifically designed to provide long, trouble-free service on heavy-duty, low speed, high torque applications. They are directly coupled to the stepper motors in the drive trains of both axes. For the azimuth system, three speed reducers with ratios 12.5:1, 30:1, and 10:1 are coupled back to back to provide a gear reduction of 3,750:1. This elaborate gear reduction system allows the drive train to move the azimuth axis of the telescope at the rate of one revolution per 23 hours 56 minutes (sidereal day) in the tracking mode and at the rate of one revolution in 25 minutes in the slew mode. One speed reducer with ratio of 15:1 is incorporated into the elevation system and is sufficient to drive the telescope at an appropriate tracking rate and at a slew rate of 10° per minute.

Position Indication Systems

Azimuth indication system. The azimuth indication system is based on measuring the rotation of an axle in the drive system with an optical incremental shaft encoder. The optical incremental shaft encoder is a noncontacting, rotary-to-digital, position feedback device mounted on the azimuth drive shaft at the stepper motor assembly. The internal monolithic electronic module converts the real-time shaft position angle, speed, and direction into TTL-compatible outputs. The encoder is used to count the rotations of the stepper motor shaft. This datum basically provides feedback as it is used to determine if the shaft rotation count is equal to the number of pulses sent to the stepper motor. The number of steps per degree of sky was empirically determined for the azimuth system. The resulting indication system provides feedback for the telescope position in azimuth to an accuracy of 0.10° and allows the telescope to position itself to any desired azimuth.

Elevation indication system. The elevation indication system is based on precisely measuring the tilt of the antenna focal plane with a high-precision biaxial clinometer. The Model 9000 precision biaxial clinometer developed by Applied Geomechanics is a low-cost biaxial clinometer designed for a wide variety of industrial and scientific applications (Figure 6). A precision electrolytic transducer comprises the sensing element. It has two orthogonal tilt angles (X and Y tilt) and one temperature channel as its output channels. The unit has an operating temperatue range of −10° to +50°C. The clinometer is mounted on the parabolic reflector of the MRT, and one of the orthogonal tilt angles (Y tilt) is used for elevation positioning. As the antenna is moved from the local horizon to the zenith, the electrolytic transducer's voltage changes accordingly; this value is collected by the computer, and the software converts this value to the degrees to determine precisely the inclination of the antenna.

MRT Receiver System

Overview. The MRT receiver system design and fabrication program was a joint effort between MSU faculty and Kruth-Microwave Electronics Company (K-MEC). The program to design, fabricate, and test a complete radio astronomy receiver system for the reception of signals in the 1,420 MHz region was undertaken in 1993 and completed in 1995. A modular, flexible approach was chosen to permit simple upgrades as evolving experimentation needs require. Standard microwave/RF components were used where possible to reduce development time and to increase reliability. Custom low-noise amplifiers were built to mate with existing antenna feed assemblies. Initial design work was performed by MSU faculty; all additional work was performed at the Maryland facilities of K-MEC. The system design is comprised of a single receiver with integral low noise amplifier directly mated to the existing waveguide flange of the MRT antenna.

System design. The overall receiver system design utilizes a low noise, sensitive, stable receiver to convert the 1,420 MHz hydrogen line frequency to a frequency region suitable for processing by standard laboratory equipment. A DC voltage derived from an envelope detector is incorporated in the final stage. In this context, low noise means less than 100 K. Ultimately, a noise factor of 40 K was attained for the receiver system. Traditionally, this would have required cryogenic cooling of the first stage semiconductor amplifier. However, advances in GaAs FET tech-

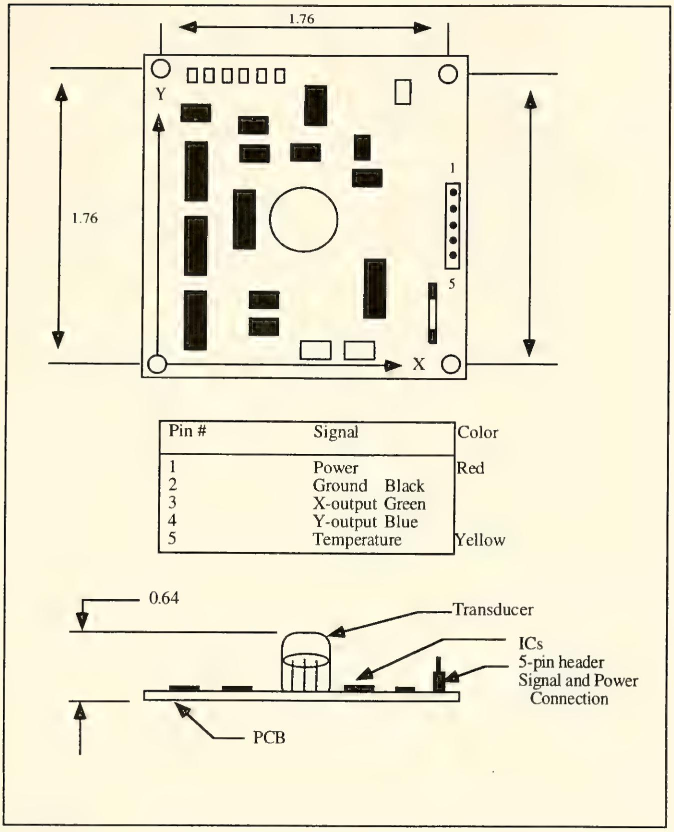


Figure 6. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. Biaxial precision clinometer basic diagram. A high precision biaxial clinometer is utilized in the elevation positioning feed-back system. As the instrument tilts in elevation, the level of an electrolytic liquid contained in a vial on the circuit board changes accordingly. This change in liquid level causes a corresponding change in potential difference among the electrodes in the vile. The circuit board then interprets this potential difference as a position angle.

nology allowed the fabrication of amplifiers with 35 K noise temperatures with the device junctions at room temperature (Kruth 1994).

The MRT receiver system incorporates a low noise Amplifier (LNA) that utilizes a field effect transistor (FET). The system is comprised of two major subsystems: the front and back-end receiver systems. The front-end receiver is mounted at the waveguide terminus mounted on the focal feed support of the MRT superstructure. A back-end, intermediate frequency (IF) processor consisting of one channel of 160-21.4 MHz and one channel of 21.4-1 MHz conversion is utilized for back-end processing with associated power supplies, monitor circuitry, and controlling computer. A block diagram of the overall system design is provided in Figure 7. Major receiver components include the following: LNA assembly, assembled with front-end receiver; receiver down converter, 1,420 MHz to 160 MHz; WJ IFC-162 160 MHz to 21.4 MHz IF converter; 21.4 MHz to baseband IF processor; Fluke 6160 synthesizer for microwave oscillator control; 5 MHz frequency standard; power supply/housing for IF processor; and miscellaneous RF circuitry, cabling, filters, attenuators, etc.

A triple conversion system is used with a first IF of 160 MHz and a bandwidth at the first IF of 23 MHz. The second conversion translates to a frequency of 21.4 MHz, with a bandwidth of 1 MHz. The frequency of 21.4 MHz is a standard IF for surveillance radios and one for which a great variety of filters (both crystal and LC) is available, so the IF

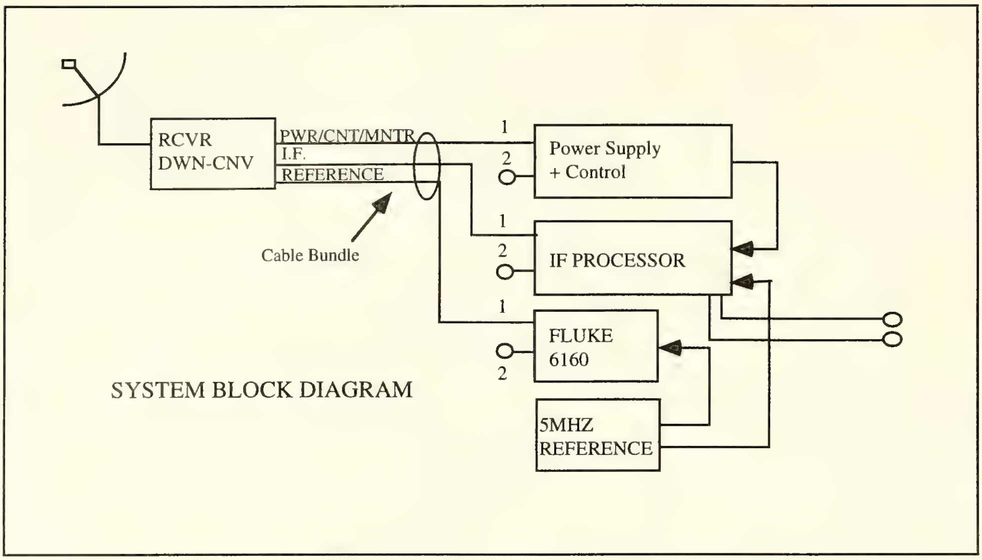


Figure 7. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT receiver system block diagram. This schematic diagram outlines the major components of the front-end and back-end receiver systems.

bandwidth can be easily modified. The final conversion is to baseband, essentially DC-1 MHz. This final conversion is easily modifiable to allow a flexible choice of final IF before detection. This strategy permits direct digitization (FFT processing on PC based platforms) as well as experimentation with parallel filter bank approaches. The receiver system consists of two major components: (1) Remote receiver front-end containing RF circuitry designed to down convert the 1,420 MHz band to 160 MHz; and (2) The back-end receiver, consisting of monitor circuitry for the converter, additional IF converter stages, reference oscillator for coherent locking of the receiver front-ends, and additional test equipment.

A key feature of this system is that all of the frequency generation components used in the various conversion stages are phase locked to common reference frequency. This reference source consists of a high-quality, 5 MHz, temperature-compensated crystal oscillator and associated buffer amplifiers. Additionally, the 5 MHz source can be derived from a rubidium or cesium beam clock, affording the utmost in stability and accuracy, if such a source becomes available. A commercial synthesizer drives the phase-locked oscillator in the remote receivers and, in turn, is locked to the 5 MHz standard. The use of a common reference frequency scheme such as this permits the remote receiver to be locked on the receive channel, regardless of external perturbations, e.g., weather conditions and seasonal temperature. This is particularly desirable in the event that a second receiver is added to the system for the purpose of interferometric measurements. This design will permit the phase coherent manipulation of the signals from the down converter box (second receiver) for interferometry-based observations and experimentation. A more detailed discussion of the circuitry and theory of operation of the front-end and back-end receivers is provided below.

Front-end receiver. The front-end receiver consists of the LNA, image reject band-pass filter, mixer, IF pre-amplifier, IF roofing filter, level set variable attenuator, IF post-amplifier, local oscillator, and required power supply regulators and control circuitry (Figure 8). The front-end receiver is housed in a box suitable for outdoor mounting at the terminus of the waveguide mounted on the antenna focal feed support structure (Kruth 1994).

High electron mobility transistor (HEMT) FET devices are used for the first stage, followed by GaAs FET gain blocks. The device utilized for the first stage application is the Nip-

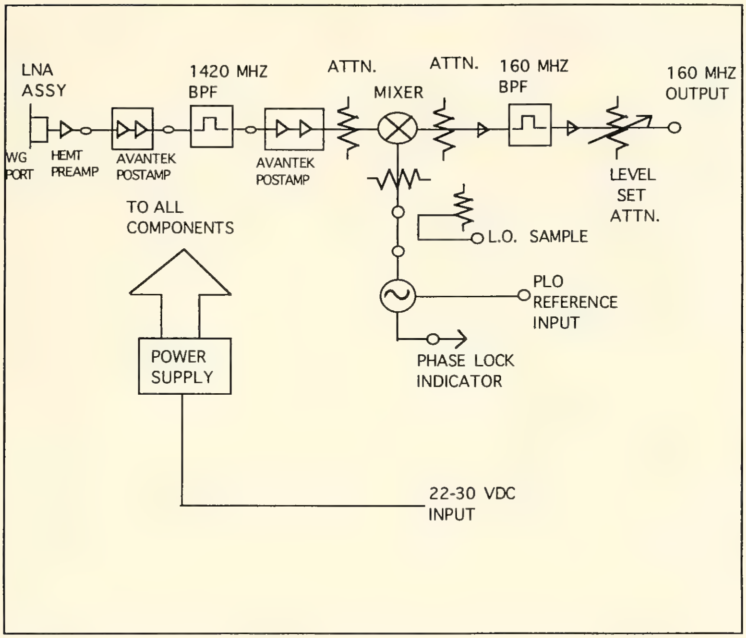


Figure 8. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. Front-end receiver diagram. This schematic diagram illustrates the major components of the front-end receiver system. The front-end receiver is a superheterodyne receiver designed around a low noise amplifier that utilizes an extremely low noise high electron mobility field effect transistor.

pon Electric Company (NEC) NE32684AF ultra-low noise pseudomorphic hetero-junction FET. This device has a measured noise figure of 0.3 dB (approximately 30 K) at room temperature, with an associated gain of 22 dB at 1,400 MHz. This value represents excellent performance. Care in the amplifier design and fabrication was exercised to preserve these values. The first stage amplifier achieves 0.5 dB noise figure and 18 dB gain using this device. The design of the input matching stage for this amplifier is critical as any losses from mismatch or attenuation may directly degrade the noise figure. A simple circuit incorporating the WG-microstrip transition is utilized, with a single tuned circuit response. With this approach, it is not possible to provide much filtering, so a filter is added between the following stages.

This stage is followed by an Avantek packaged gain block pair consisting of a UT02012 and a UT02013 amplifier cascade. This combination provides good gain (20 dB), excellent intercept point (P-sat = +21 dBm fundamental), and a modest noise figure of 2.5 dB. This effectively controls the noise figure degradation due to second stage contribution. Due to the high gain and wideband nature of the first stage amplifier, a front-end pre-selection filter is necessary to block out terrestrial interference. This interference is from diverse sources such as TACAN, radar, cellular phone harmonics, INMARSAT uplinks, and others. The bandwidth of the selected filter is on the order of 150 MHz, centered at 1,420 MHz; the insertion loss is 2 dB. A standard double-balanced mixer is used for the first converter stage. A standard drive level type is appropriate to this application; the conversion loss is 6 dB.

The 160 MHz IF amplifiers are of conventional design. A coaxial bandpass filter is used to establish the bandwidth of the first converter system. Since the desired bandwidth is 2 MHz, a filter of at least five times this value must be used to permit future expansion of the experimental system. The bandwidth of the system is preserved down to the final stage; it is possible to use wider filters should experimental needs require. A 2 MHz filter is

used to preserve the 2 MHz system bandwidth all the way down to final detection.

The level set attenuator that is included in the design allows manual control of the gain of the receiver in order to coarsely equalize the gain of the two receivers when used together. Fine gain is controlled in the IF processor system. The calculated end-to-end gain of the front-end is 68 dB. The calculated noise figure is 0.535 dB based on a 0.5 dB first stage and a 2.5 dB second stage. An overall noise figure of <0.4 dB (approximately 40 K), was attained.

The local oscillator, a phase-locked (PLO) cavity tuned type made by California Microwave, utilizes a "brick" style oscillator. This oscillator is a fundamental L band cavity using a low noise bi-polar transistor as the oscillator element. It incorporates a reference multiplier/harmonic mixer arrangement to permit locking. The oscillator is driven by a synthesizer at 105.0835 MHz and, as the PLO assumes the phase noise and stability character of the oscillator directly, a reference signal of high quality is therefore produced.

The front-end receiver package is housed in a waterproof aluminum box approximately 12 in^3, with all electrical connections made on one face. Thermal insulation and heating blankets are used to provide a relatively constant temperature environment for the outdoor receiver unit. An integral power supply that operates from 22–30 VDC, and uses well-filtered, regulated DC-DC converters provides the various voltages required by the system. This permits a single low-voltage feed to the receiver package, for simplicity and safety.

Back-end receiver. The back-end receiver is comprised of a synthesizer used to generate reference signals for the down-converter, an IF processor with crystal oscillator for conditioning of the IF signal, a down-converter power supply, an optoisolation system, a controlling computer, and interface device. A high-quality Fluke synthesizer that can generate the 105 MHz range reference signal for the receiver converters is incorporated into the back-end receiver system. This is an adaptation of the popular 6160A series that has been modified to use an external 5 MHz standard. The output of the remote receiver at 160 MHz is transmitted by low loss 50 ohm coaxial cable to the indoor rack. Here the signal is buffered and split. A sample of the 160 MHz "wideband" IF is available on the front panel of the control box. The other leg of the power splitter is applied to the 160-21.4 MHz IF converter system. This system element used is a Watkins-Johnson IFC-162 IF converter module, a self-contained system. This device converts the signal to a frequency of 21.4 MHz without degrading the signal-to-noise ratio. The internal crystal oscillator used to convert the signal was modified so that the signal can be phase-locked to the reference 5 MHz oscillator. Refer to Figure 9 for a schematic diagram of the back-end receiver (Kruth 1994).

Additional filtering is then used to establish the desired final bandwidth before detection. The final conversion brings the 21.4 MHz down to "baseband" by beating against a crystal-controlled oscillator. The frequency of the synthesized oscillator can be changed, along with the 21.4 MHz filtering, to allow observations at different bandwidths at the final detection stage. Buffered sample ports are available at all pertinent points in the signal path for access to the signal. This is a useful feature for built-in tests as well as experimentation. The complete receiver system concept is shown in block diagram form in Figure 7, which provides an overview of the interconnection of the various system elements. A regulated high current supply provides 26 VDC nominal for operating the outdoor receiver package.

A calibrated semiconductor noise source is incorporated into the front-end LNA waveguide port of the receiver package to inject a precise amount of excess noise for calibration purposes. A precision coupler and attenuator is used to precisely set the injection level of the noise source into the first amplifier. The coupler was manufactured as part of the amplifier to minimize the impact of additional insertion loss. In fact, the scheme used did not noticeably denigrate the noise temperature.

MRT Operator Program

The computer operator program developed for the MRT is responsible for positioning the telescope in azimuth and elevation, tracking of cosmic objects as the sky apparently rotates, determining telescope position in altitude and azimuth via independent feedback loops, and controlling data collection and storage in ad-

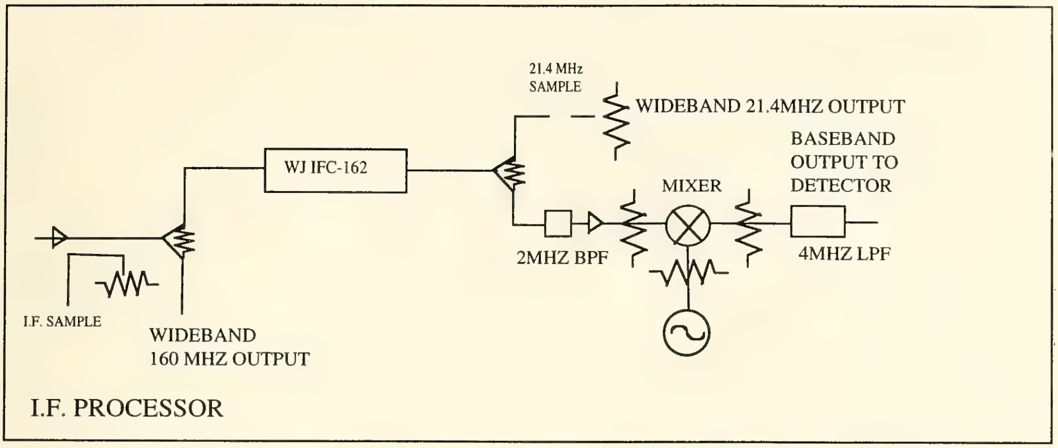


Figure 9. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. Intermediate frequency (IF) processor block diagram. The IF processor is designed around an internal crystal oscillator phase-locked to an external reference 5 MHz oscillator. The 160 MHz IF signal is mixed with the internally generated signal and down-converted to 21.4 MHz. The final conversion brings the 21.4 MHz signal down to baseboard by beating against a controlled crystal oscillator. The synthesized oscillator can be adjusted to allow different bandwidths at the final detection stage.

dition to controlling additional experimental parameters. The initial design of the controlling program was developed by MSU students and faculty. The program has evolved from its initial design in order to compensate for operational characteristics of the positioning systems, which have developed as these systems have matured. This evolution has been carried out by students, along with MSU staff, after performing operational tests of the positioning system components.

The controlling program has been developed with the Labview Virtual Instrumentation software package, which provides a graphical programming environment "G," with built in accessibility to the functions of the National Instrument's LAB NB interface card. The graphically intensive language "G" is ideally suited to the production of programs used in data collection and analysis as it was initially designed to communicate with interface technologies. Virtual instruments developed with this package actually mimic hardware components such as spectrum analyzers and oscilloscopes by conditioning the signal in exactly the same way that the hardware counterpart would. This package reduces the need for expensive and space-consuming hardware.

The program determines positioning requirements based on the current Universal Time, as well as the destination coordinates (right ascension and declination) provided by the operator. After determining the local sidereal time based on this input data, and converting the coordinates of the object of interest to its current azimuth and altitude, the operator program provides the necessary control signals to the azimuth and elevation translators via digital I/O ports on the interface card. The necessary positional accuracy is achieved by monitoring the azimuth encoder and elevation clinometer. Positional accuracy of 0.10 arcdegrees is achieved via this feedback loop.

The operator program performs transit operational mode by positioning the antenna to the target location, then monitoring the analog signal from the receiver. Tracking mode additionally incorporates an algorithm to monitor the deviance of the antenna's position from the desired position, with the intention of achieving the aforementioned positional accuracy. It was necessary for the operator program to evolve based on experiments performed with the mechanical elements of the positioning system. The number of TTL pulses required to position the telescope in elevation and azimuth was determined empirically from numerous experiments. These values were then programmed into the program to automate positioning of the telescope. Schematics of the major components and al-

ogrithms of the operator program are provided in Figures 10 through 12.

THEORETICAL PERFORMANCE CHARACTERISTICS OF THE MRT

The minimum detectable flux density, the weakest detectable radio frequency signal from space (Δs_{min}), expressed in Janskys (1 Jansky = 10^{-26} w m^{-2} Hz^{-1}) may be calculated (Kraus 1986):

$$\Delta S_{min} = \frac{2KKsT_{sys}}{\epsilon_{ap}A\sqrt{(\Delta v \Delta t)}}$$

where:

ΔS_{min} = minimum detectable flux density

Ks = receiver constant ($\cong 1$)

T_{sys} = system temperature

K = Boltzman's constant ($1.38 \cdot 10^{-23}$ J·K^{-1})

ϵ_{ap} = aperture efficiency ($0 < \epsilon_{ap} < 1$) dimensionless

A = aperture area (m^2)

Δv = pre-detection bandwidth in Hz

Δt = post-detection integration time

Values for the MRT subsystems are obtained from laboratory measurements of the MRT front-end receiver furnished by Kruth Microwave Electronics Corporation (K-MEC); values for the antenna system are taken from AORG (1968). The following values are substituted:

T_{sys} = 67.77K

Δv = $2 \cdot 10^6$ MHz

Ks = 1

ϵ_{ap} = 0.65

A = 38 m^2

These values produce a value of 5.35 * 10^{-26} J = 5.35 Janskys assuming a one-second post-detection integration time.

The total system temperature (T_{sys}) including noise contributions due to the waveguide and other factors is described by (Kraus 1986):

$$T_{sys} = T_A + T_{Lp}[(1/\epsilon) - 1] + (1/\epsilon)\,T_R$$

where:

T_{sys} = system temperature

T_A = antenna temperature

T_{Lp} = physical temperature of waveguide

ϵ = transmission efficiency

T_R = receiver temperature

Values:

T_R = 40.31° (from Kruth Microwave Electronics Corp. K-MEC)

ϵ = 0.9923 (from MDL Component) Book (Waveguide Manufacturer)

For WR-650, Aluminum Loss[a]

0.233 dB/100 at 1,421 MHz

15′ of W.G. = 0.3345 dB loss

Assume for dipole array efficiency = 50%

Efficiency of WG = 10(−loss/10)

= 10(−0.03345/10) = 0.9923

T_{Lp} = 290°

T_A = 25° (see below)

The antenna temperature (T_A) was calculated in the following manner (5):

T_A = 3K (3K cosmic microwave background radiation)

3K (atmosphere)

2K (scattering from feed support structure)

2K (diffraction spillover to ground)

5K (Ohmic losses)

$\Sigma = \frac{10K}{25K}$ (scattering by inappropriate surface geometry)

Applying these values gives:

$$T_{sys} = 25° + 2.242° + 40.31° = 67.73°$$

Solving for the minimum detectable cosmic temperature:

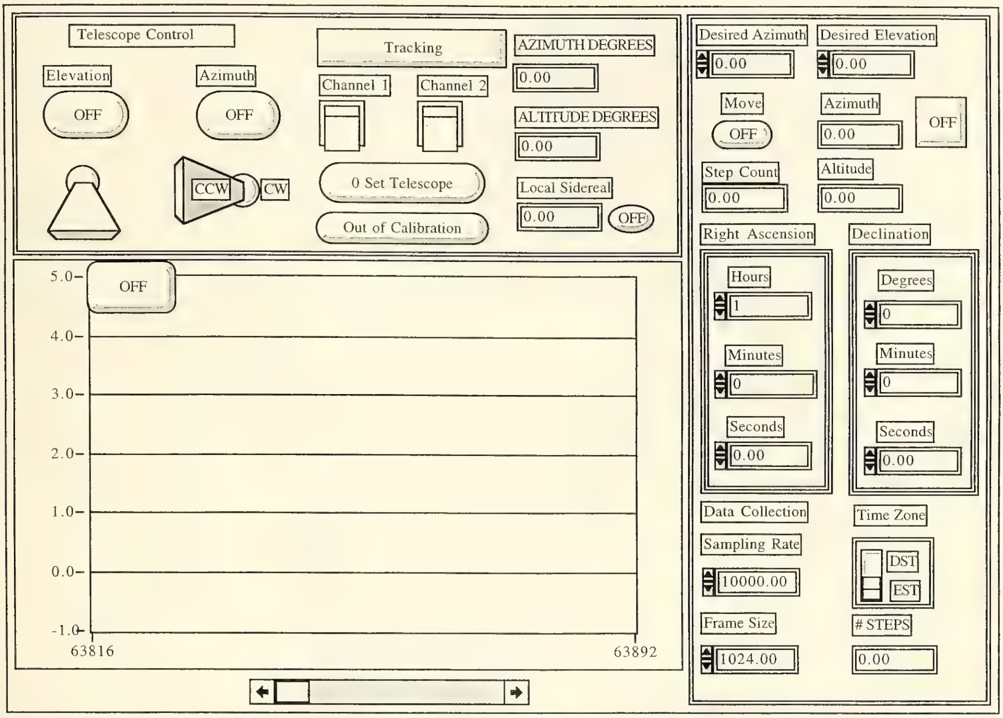


Figure 10. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT operator program positioning system front-end. The MRT operator program utilizes virtual instruments that incorporates a strip chart recorder with the positioning and data collection system. The user-end control panel is shown in the diagram.

$$\Delta T_{min} = \frac{Ks \cdot T_{sys}}{\sqrt{(\Delta v)(\Delta t)}} = 0.04787° \text{ K}$$

Recalculated system minimum sensitivity:

$$\Delta S_{min} = \frac{2K[\Delta T_{min}]}{\epsilon_{ap} A}$$

$$\Delta S_{min} = 5.349 \times 10^{-26} = 5.35 \text{ Janskys}$$

The spatial resolution (expressed as half-power beamwidth-HPBW) is determined from the following relationship:

$$\text{HPBW} = \frac{58\lambda(\text{m})}{\text{D(m)}}$$

where:

HPBW = Half-power beamwidth in degrees

λ = Operating wavelength in meters

D = Aperture diameter in meters

Calculation of the HPBW of the existing MRT system must be performed in two steps as the antenna is symmetric about a major and a minor axis (Malphrus and Bradley 1987).

HPBW of the Major Axis:

$$\text{HPBW} = \frac{(58)(0.211 \text{ m})}{13.42 \text{ (m)}}$$

$$\text{HPBW} = 0.91192°$$

Repeating the calculation for the minor axis reveals:

$$\text{HPBW} = \frac{(58)(0.211 \text{ m})}{3.355 \text{ (m)}}$$

$$\text{HPBW} = 3.647°$$

SCIENCE PROGRAMS

The MRT will be employed in a widely varied scientific program. Research programs will range from investigating single cosmic phenomena to measuring secular variation of radio sources to mapping structures and areas of sky. The MRT will be utilized in research programs in planetary, galactic and extraga-

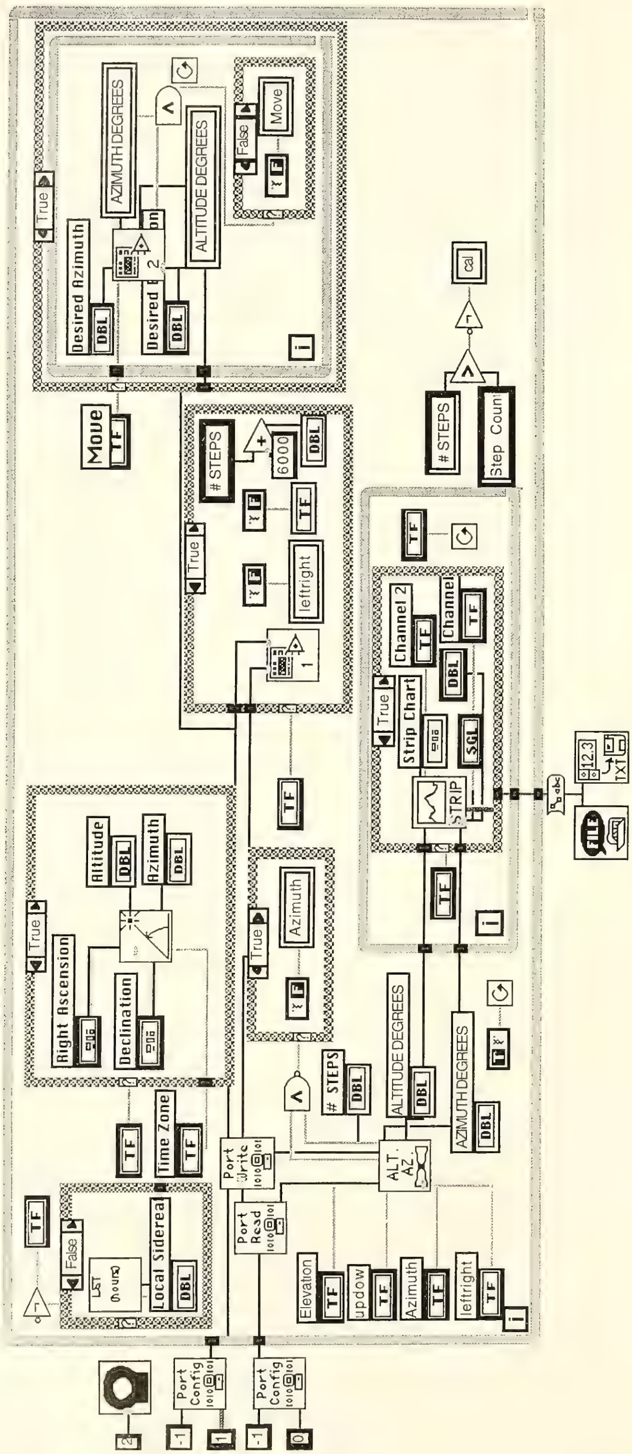


Figure 11. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT operator program positioning system back-end. The MRT operator program utilizes virtual instruments written in a graphical language, "G." The code for the user-end control panel is shown in the diagram.

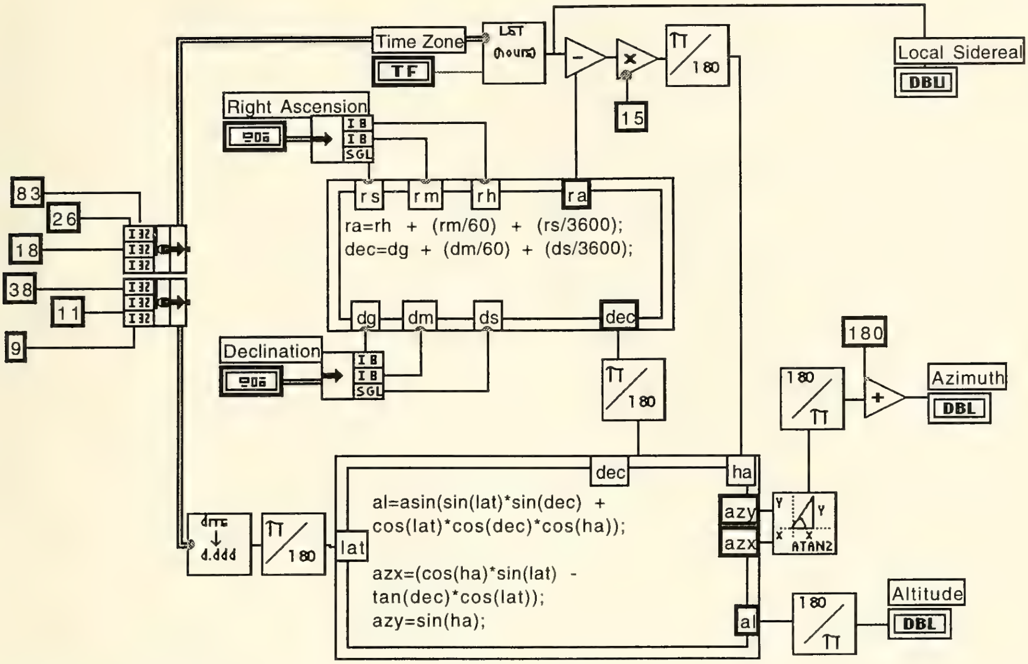


Figure 12. Morehead Radio Telescope, Morehead State University, Morehead, Kentucky. MRT operator program azimuth and elevation subroutine. The azimuth and elevation subroutine is responsible for converting the celestial object's coordinates in right ascension and declination to local azimuth and elevation and for sending pulses to the translators to position the telescope in azimuth and elevation.

lactic astronomy and in SETI Searches. Research programs will include observing distant galaxies for variability, mapping regions of the Milky Way, spectral analyses of cosmic phenomena, and measurement of galactic rotation utilizing measurements of the Doppler shifts of hydrogen clouds in galactic spiral arms. Astrophysically interesting phenomena such as quasars, radio galaxies, supernova remnants, giant molecular clouds, HI regions, cosmic masers, and exotic stars such as neutron stars and possible black holes will be investigated.

Research programs will include observing distant galaxies for variability, mapping regions of the Milky Way, spectral analyses of cosmic phenomena and, galactic rotation and dynamics. Astrophysically interesting phenomena will be investigated including quasars, radio galaxies, supernova remnants, giant molecular clouds, HI regions, cosmic masers, and exotic stars such as neutron stars and black hole candidates.

CONCLUSIONS AND PROJECT SIGNIFICANCE

The demilitarization initiatives that the U.S. government has undertaken have recently produced a surplus of high-tech military equipment. Many U.S. scientists have begun to take advantage of the demilitarization efforts by acquiring and modifying surplus military equipment for use in scientific research projects. The MRT project is a classic example of the re-utilization of surplus high-tech equipment for basic science research. The success of the MRT project depends on the validity of the scientific results produced by the various research initiatives undertaken with the instrument. This validity of the scientific results is directly related to performance characteristics of the instrument. Radio telescopes are generally rated among the largest and most sensitive scientific instruments ever produced. The scale and sensitivity of instruments is necessitated by the phenomenally weak radiation

they collect from space. In point of fact, the flux density of even a moderately strong cosmic source at 1,420 MHz (the central operating frequency of the MRT) is on the order of a few Janskys (Jansky = 10^{-26} W/m^2/Hz). An analogy that radio astronomers use to describe the weak signals detected by these instruments from space is to imagine converting the electromagnetic radiation into mechanical energy. If one converted all of the electromagnetic radio frequency radiation from space collected by all the radio telescopes from all over the world since the inception of the science in 1932, and converted this energy into mechanical energy, it would roughly be the equivalent kinetic energy contained in a falling snowflake. If this energy were converted into electric energy it would light a 100-watt light bulb for almost 1 second (Malphrus 1996). Because of the inconceivably weak radiation, the performance characteristics of the radio telescope must be conform to research-grade specifications to perform valid science. The instrument's performance characteristics—specifically antenna gain, minimum detectable flux density, and spatial resolution—are critical characteristics affecting the scientific results of a given research project. Experiments designed to measure these performance characteristics empirically are implicated.

ACKNOWLEDGMENTS

Funding for the MRT was provided by the National Science Foundation's Instrument and Laboratory Improvement program and Morehead State University. Numerous individuals have been involved in the design and development of the instrument's many subsystems and have provided materials and services: Joe Planck, Porter Dailey, Steve Leitz, Gene Caudill from Physical Plant, Morehead State University; Ms. Regina Kissick, Department of Physical Sciences; and Dr. Ronald Eaglin, president, Dr. Gerald DeMoss, dean of the College of Science and Technology, and Dr. J.C. Philley, vice president of academic affairs, Morehead State University.

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Abstracts of Some Papers Presented at the 1997 Annual Meeting of the Kentucky Academy of Science

AGRICULTURAL SCIENCE

Botanical vs. synthetic insecticides. GEORGE F. ANTONIOUS, Community Research Service, Atwood Research Facility, Department of Plant and Soil Science, Kentucky State University, Frankfort, KY 40601.

Changes in pesticide formulations and the use of restrictions have greatly reduced pesticide levels in field water released into public waterways and consequently have reduced the adverse impact to resident fish species and other aquatic life. Interest in the use of botanical insecticides (BIs) has grown over the last decade. BIs are now applied in the United States to control insect pests of vegetables; most home gardeners and small organic farmers are flocking back to botanical. However, no matter how promising BIs seem from the entomologist's point of view, persistence of BIs in soil and water under field conditions has to be tested. At Kentucky State University (KS) Research Farm, we conducted an experiment to study the behavior of the active ingredients of two formulations, a botanical insecticide containing pyrethrin (Py's) and piperonyl butoxide (PBO) and a synthetic insecticide (Thiodan 3EC) containing α- and β-endosulfan. Our objectives were to study movement of the active ingredients at trace levels in soil and their loading to natural surface runoff water following spraying on highly erodible land. The low residues of total Py's detected in soil and runoff water and their low toxicity to mammals should cause little environmental concern. Py's are encouraging as alternative insecticides.

Comparison of creeping bentgrass green varieties and Bermudagrass fairway varieties in southern Kentucky. D.I. SOLBERG, H. LIU,* and P. DOTSON, Department of Agriculture, Western Kentucky University, Bowling Green, KY 42101.

Southern Kentucky belongs to the transition zone for turfgrass growth. Both cool season and warm season turfgrasses can grow in the region but are subjected to heat stress for cool-season turfgrasses and cold stress for warm-season turfgrasses. The objective of our study was to compare four creeping bentgrass *(Agrostis palustris)* cultivars ('Pennlinks', 'Penncross', 'Crenshaw', and 'Cato') used as golfcourse putting greens and among three Bermudagrass *(Cynodon dactylon)* cultivars ('419', 'Quicksand', and 'Vamont') used as fairways under high maintenance in southern Kentucky. The study was done at the Western Kentucky University Farm, Bowling Green. The greens and fairways were built in 1994. Weekly evaluation of turf quality, color, percent coverage, and pest problems were conducted from February to October 1997. 'Penncross' and 'Pennlinks' had the best performance as putting-green grasses. 'Crenshaw' showed more dollar spot than others. 'Cato' ranked lowest among the four cultivars of creeping bent. There were no significant differences among the three Bermudagrass cultivars. However, 'Quicksand' exhibited the earliest spring green-up. Evaluation will be continued through the next growing season.

Constructed wetlands for water quality improvement. GEORGE F. ANTONIOUS,* FRANK YOUNG, and MATTHEW E. BYERS, Community Research Service, Atwood Research Facility, Department of Plant and Soil Science, Kentucky State University, Frankfort, KY 40601.

Kentucky is generally a rural state. In areas where municipal sewage is not an option because the bedrock is near the surface and infiltration is impossible or the water table is high and contaminants can be discharged directly to the groundwater, onsite constructed wetlands systems are appropriate. These systems are natural means of wastewater treatment at the site of origin and have tremendous biological and biochemical activity for the degradation and decomposition of toxic organics, nutrients, and pathogenic bacteria. To monitor the efficiency of constructed wetland systems in Kentucky, four homeowners installed and maintained systems that were sampled and monitored for temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), orthophosphate (PO_4 ion), and fecal coliform (FC) bacteria. Water quality data were statistically analyzed using an analysis of variance to test the influence of sampling date, individual system sampled, and port distance within each system with respect to the septic tank on concentration of the tested parameters. The studied systems provided good reductions in concentrations of TSS and BOD and had satisfactory FC bacteria reduction potential but were less effective in nutrient removal. Further research work in the system design is needed to increase efficiency for NO_3-N, FC, and PO_4 removal.

Onsite constructed wetland demonstration. FRANK S. YOUNG III,* GEORGE F. ANTONIOUS, and MATTHEW E. BYERS, Community Research Service, Atwood Research Facility, Kentucky State University, Frankfort, KY 40601; MICHAEL DAVIS, Department of Technical Education, Kentucky Tech Anderson Technology Center, Lawrenceburg, KY 40342.

Many of Kentucky's residents still reside outside of large metropolitan areas and prefer to live in the rural countryside where city sewer is not an option. A conventional onsite wastewater treatment system for these families is a septic tank for the collection and retention of solids and sludge, in combination with a lateral drainage field for the distribution and further treatment in optimal soils. Of

Kentucky's 600,000 onsite treatment systems 70% are located in soils that are less than optimal for which these systems were designed. That means an estimated 420,000 systems contribute to the non-point source pollution problems. Many of these failures are due either to a geological failure or straight pipe disbursement directly into streams and rivers. The discharge from these systems consists of a highly concentrated combination of pathogenic bacteria, nitrogen rich nutrients, and organic pollutants. An onsite constructed wetland system as an alternative to conventional leachfield treatment can reduce environmental health problems. At Kentucky State University Research Farm, a wetland is being constructed consisting of two 6′ × 30′ trenches excavated to ca. 18″. The first trench is lined with a black plastic liner. The trenches were partially filled with crushed limestone to 14″ and then capped with a smaller size rock. Influent will flow through the constructed wetland cells whereby septage will flow via positive displacement being treated by microbes and the roots of the aquatic macrophytes. A third cell consisting of a trench like the first will be used for further treatment of the effluent coming from the first two cells. Two different types of distribution fields will be utilized to compare serial vs. parallel distribution. Constructed wetlands give hopeful potential to Kentucky's future in onsite sewage recycling.

BOTANY & MICROBIOLOGY

Confirmation of extrafloral nectar on *Heliconia latispatha* (Heliconiaceae). THOMAS C. RAMBO, C. TONY R. HAMPTON, ELINOR E. RAMBO, and TODD N. BEZOLD, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Heliconia latispatha has been shown to attract ants, mosquitoes, and other insects to supposed extrafloral nectaries on the external surface of the terminal bud of the inflorescence, but the presence of extrafloral nectaries has not been confirmed. A closely related species, *H. imbricata*, does not attract insects and has been assumed to lack extrafloral nectaries. At Estación Sirena, on the Osa Peninsula of Costa Rica, 10 *H. latispatha* and 20 *H. imbricata* plants were selected and monitored for insect visitors hourly from 0530–0930 and from 1330–1730. After 5 days, a sugar solution was applied daily to 10 of the *H. imbricata* buds at 0600 and 1400, and insect visitors were recorded for an additional 5 days. The *H. latispatha* attracted insect visitors throughout the test period; the *H. imbricata* with no added sugar did not attract visitors; the *H. imbricata* to which sugar was added attracted insects briefly, but the effect did not last more than 2 hours. These results confirm the lack of extrafloral nectaries on *H. imbricata*; if any nectar were present, the buds would have regular insect visitors. These results also confirm that *H. latispatha* produces nectar throughout the day, since insects were always present. Small samples of nectar from *H. latispatha* buds were obtained and tested with a field refractometer for sugar concentration. The samples showed a range of 3% to 15% sugar, confirming that *H. latispatha* does indeed produce extrafloral nectar.

Forest sedges (*Carex*, Cyperaceae) of 10 Kentucky State Nature Preserves. ROBERT F.C. NACZI* and LORI A. HEEG, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Sedges (*Carex*, Cyperaceae) comprise the largest genus of flowering plants in Kentucky, with about 125 species in diverse habitats in the state. Despite their taxonomic and ecologic importance, sedges are poorly known. We investigated forest sedges by sampling 10 Kentucky State Nature Preserves with widely varying sizes and locations but similar dominant vegetation (mesic forests): Audubon (Henderson County), Blanton Forest (Harlan Co.), Blue Licks (Robertson Co.), Brigadoon (Barren Co.), Cumberland Falls (McCreary Co.), Floracliff (Fayette Co.), Natural Bridge (Powell Co.), Pine Mountain (Bell Co.), Quiet Trails (Harrison Co.), and Vernon-Douglas (Hardin Co.). Our goals were to assess sedge diversity, abundance, and geographic distributions, which we accomplished through intensive field work in late spring and early summer 1997. In all, we observed 55 species of sedges (44% of Kentucky total). The preserves with the highest diversity were Quiet Trails, Cumberland Falls, and Natural Bridge (28, 24, and 23 species, respectively). Audubon, Blue Licks, and Blanton Forest had the fewest species (3, 6, and 9). Species-area relationships reveal that the relatively small Quiet Trails (45 ha) had higher than expected diversity and the large Blanton Forest (435 ha) had lower than expected diversity. We observed no state endangered or threatened species. However, we encountered four species previously recorded from five or fewer counties. Forty-five of our collections appear to be new county records. The highest proportion of county records come from Audubon (100%), Quiet Trails (90%), and Blue Licks (80%), indicating Henderson, Harrison, and Robertson counties, respectively, merit additional floristic investigation.

Genotypic and phenotypic variation found in isolated populations of *Spiraea virginiana* (Rosaceae). CONSTANCE M. ANDERS* and ZACK E. MURRELL, Department of Biology, Western Kentucky University, Bowling Green, KY 42101.

Spiraea virginiana Britton is a federally listed rhizomatous shrub endemic to the southern Blue Ridge and Appalachian Plateau provinces. The typical habitat of *S. virginiana* is along scoured sections of high-gradient streams. Present evidence indicates that the species does not reproduce sexually. No viable seeds or seedlings have been found in the wild, suggesting that populations within drainages are products of vegetative reproduction, most probably occurring when rhizomes broken loose from upstream populations wash downstream to form new ramets. There is considerable confusion, therefore, regarding identification of individuals and thus no known mecha-

nism for evaluating population size and structure. Phenotypic variation in *S. virginiana* was examined through a morphometric examination of leaf size and shape, using Morphosys to make 25 leaf measurements. These data were analyzed using Principal Components Analysis, to identify any morphological variation within and between drainages. We are currently examining genetic identity across the distribution using Randomly Amplified Polymorphic DNA (RAPDs), in an attempt to evaluate the genetic diversity. Genetic uniformity among the drainages would suggest that either extant populations are the ancestors of migrants that persisted through the glacial maximum in the watershed of the Gulf of Mexico, or they are the products of a severe bottleneck during the Hypsithermal Period. Genetic variation among the drainages would suggest that *S. virginiana* persisted through the last glacial maximum within the present day drainage systems, supporting Ogle's hypothesis that the present distribution of *S. virginiana* represents the remnants of a more widespread distribution in the past.

Infrageneric relationships, populational biology, and mode of speciation in the North American fern genus *Pentagramma* (Pteridaceae). MARK C. JENSEN, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

The relative frequency of different modes of speciation in plants has been the subject of considerable speculation. On the basis of geographical distribution, allopatric speciation by subdivision has been considered most frequent. However, due to the theoretical difficulty of transforming widespread population systems through gene flow or selection, other authors have argued that geographically local models of speciation (e.g., the peripatric model) are more likely. Empirical evidence is clearly required to address this question, yet the kinds of data required are available for few, if any, plant groups. I have tested for the operation of allopatric versus local modes of speciation in the fern genus *Pentagramma* by searching for predicted genetic "signatures" of speciation. Analyses based on nuclear DNA sequencing, chloroplast DNA restriction sites, and chromosome number have been used to elucidate the evolutionary relationships in this group. The populational genetic structure in these taxa based on isozyme electrophoresis analyses has been used to quantify the richness and distribution of allelic variation and to assess the manner in which genetic diversity is partitioned among different populations, subspecies, and species. Few studies of homosporous ferns have combined a molecular phylogenetic approach with an analysis of their populational genetic structure, yet this combined approach is necessary to reliably infer the mode of speciation.

In search of *Vibrio fischeri* lux homologues in *Edwardsiella ictaluri*. EDWARD TODD JACOBS and GEOFFREY W. GEARNER,* Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

Autoinduction is a sensing mechanism employed by certain bacterial species to monitor their own population density. These bacteria produce a compound called autoinducer, which is permeable to the cell membrane and will accumulate in the surrounding environment. If extracellular concentrations rise high enough, autoinducer will diffuse back into the bacterial cells and turn on genes required for certain bacterial behaviors. One of the best characterized autoinduction systems is that of the marine bacterium *Vibrio fischeri*. *Vibrio fischeri* uses autoinduction to regulate the lux operon, which encodes bioluminescence enzymes. In the free-living state, autoinducer concentrations never rise in the cell, and the bacterium does not produce light. In the host-associated state where cell densities are great, bioluminescence is expressed. Certain pathogenic bacteria use autoinduction systems to regulate the expression of virulence factors. In our study, a 32P-labeled ssDNA probe exhibiting sequence identity with the luxR gene was used to probe restriction enzyme-digested *Edwardsiella ictaluri* DNA. The objective was to address the question, does *E. ictaluri*, a problematic channel catfish bacterial pathogen, possess autoinduction regulatory elements that regulate the gene expression of a virulence factor? Southern blot data showed that the luxR probe annealed to a 8.8-kb Sal I fragment of *V. fisheri* DNA but did not hybridize with *E. ictaluri* DNA. Our work was supported by the Kentucky Academy of Science Marcia Athey Fund and Morehead State University.

Isozyme comparison of a putative hybrid (*Heliconia imbricata* × *H. latispatha*; Heliconiaceae) with its parent species through use of starch gel electrophoresis. C. TONY R. HAMPTON,* THOMAS C. RAMBO, TODD N. BEZOLD, and ELINOR E. RAMBO, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Genetic analysis of a putative hybrid (*Heliconia imbricata* × *H. latispatha*) was done with starch gel electrophoresis to detect variations in isozymes. Young unfurled leaf tissue was collected from 35 individuals of the parent species and 6 putative hybrids, stored in liquid nitrogen, and transported to the National Museum of Natural History for genetic analysis. Two enzyme systems were run (Aconitase, Isocitrate Dehydrogenase). The resulting data suggest that the putative hybrid is an F_1 hybrid between the parent species. Morphological data reinforced the electrophoretic data.

Morphological comparisons of *Heliconia latispatha*, *H. imbricata*, and their putative hybrids (Heliconiaceae). TODD N. BEZOLD,* TONY R. HAMPTON, and THOMAS C. RAMBO, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Morphological characteristics of *Heliconia latispatha*

and *H. imbricata* were compared with those of putative hybrids between these species. Data were collected from 35 individuals of *H. latispatha*, 35 *H. imbricata*, and 6 hybrids. Besides plant height and the middle bract's orientation to the rachis, the height, width, length, pubescence, and color of vegetative and reproductive structures were measured. Perianth and staminode morphology was recorded. Data were analyzed using Kruskal-Wallis one-way non-parametric AOV. Morphological characteristics between progenitors proved to be significant. The hybrids share characteristics with one or the other parent. No significant difference was found between the hybrids and *H. latispatha* in perianth length, bract orientation, and drupe length and width. With *H. imbricata*, the hybrids share bract width and petiole length. The hybrids exhibit intermediacy between the progenitors in petiole and rachis diameter, bract length, and leaf blade width. They often grows among patches of *H. imbricata* in shaded areas. The absence of *H. latispatha* may indicate succession, since this species prefers sunny locations. Phenotypic variability exists within *Heliconia* species, especially *H. latispatha*. A particular genotype of *H. latispatha* may be the contributor to hybrid crossing, since sites with both parents exist without any hybrids.

Morphometric studies of the *Sphagnum cuspidatum* complex: the *S. trinitense/S. mississippiense* species pair. ALLEN C. RISK, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

The *Sphagnum cuspidatum* complex is a taxonomically difficult group of peat mosses. Members of the complex are distinguished from other section *Cuspidata* species by branch leaves noticeably elongated toward the branch tips, deltoid to ovate-deltoid stem leaves with obtuse to acute apices, and branch leaf hyalocysts with few pores. The *S. trinitense/S. mississippiense* species pair is distinguished from other members of the complex by denticulate to serrulate branch leaf margins, features of the stem hyalodermis, and branch leaves appressed when dry. *Sphagnum mississippiense* was described in 1987 as a species endemic to southern Mississippi and eastern Louisiana and distinguished from *S. trinitense* on the basis of branch leaf shape. The results of morphometric analyses (various univariate analyses and principal components analysis) of 35 herbarium specimens (including three paratypes of *S. mississippiense*) identified as either *S. trinitense* or *S. mississippiense* from southern Mississippi and eastern Louisiana did not support the recognition of two taxa. Characters such as branch leaf length, branch leaf width, and branch leaf length-to-width ratio exhibited continuous variation across the specimens. Specimens identified as *S. mississippiense* are interpreted as representing variation within *S. trinitense*.

Phylogenetic placement of African *Cornus* (Cornaceae): evidence from nuclear rDNA. SCOTT A. MYERS* and ZACK E. MURRELL, Department of Biology, Western Kentucky University, Bowling Green, KY 42101.

The genus *Cornus* (dogwoods) contains 50 species that have been divided into nine subgenera. One of these species, *C. volkensii*, has been segregated into the subgenus *Afrocrania*. Previous studies combined morphological, anatomical, and chemical data to produce a hypothesis of evolutionary relationships that placed the subg. *Afrocrania* as a segregate lineage sister to the subg. *Cornus*, and placed the *Afrocrania/Cornus* lineage sister to the big bracted dogwoods. The subgenus *Afrocrania* has been examined morphologically, anatomically, and palynologically; however, it was not sequenced in Xiang's analysis of *rbc*L (chloroplast) sequence data, or in her analysis of the *matK* region of chloroplast DNA. Murrell's earlier analysis of the Internal Transcribed Spacer (ITS) region of nuclear ribosomal DNA included sequence data for *C. volkensii*, but these data were suspect due to inconsistencies with the sequence data for members of the subg. *Cornus*. We amplified both ITS regions from the subg. *Afrocrania* using the external primers 4 and 5 and the Polymerase Chain Reaction (PCR) and consistently obtained two distinct migrating bands approximately 750 bp in length. We cloned these amplified regions in an attempt to isolate these disparate bands for sequencing. Analysis of the sequence data suggests that the evolutionary origin of the African dogwood was not with the cornelian-cherries but was basal to the red-fruited clade of dwarf dogwoods, cornelian-cherries, and big-bracted dogwoods; however, analysis of these data may be complicated by the problem of long branch attraction. These results suggest a need to reexamine fruit development and inflorescence structure in subg. *Afrocrania* and *Cornus*.

Plant and soil changes during 39 years of succession on coal spoil in southern Ohio. JOE E. WINSTEAD,* Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351; JOHN T. RILEY, Department of Chemistry, Western Kentucky University, Bowling Green, KY 42101.

Of 1958 origin, an unreclaimed strip mined coal spoil bank in Vinton County, Ohio, has been studied at 3-, 13-, 23-, 33-, and 39-year intervals measuring vegetational and soil changes along a 40-m transect and permanent plots. The site was initially invaded by *Andropogon, Solidago, Bidens,* and *Danthonia* species; tree cover dominated by *Acer, Liriodendron,* and *Platanus* species has developed on an area more stabilized than most of the overburden resulting from mining activity. Analysis of soil samples collected during the study indicates a decline in acidity, a rise in nitrogen levels, and a consistent high level of sulfur in the substrate supporting vegetational development. Physical change from erosion and instability of the rock and coal shale substrate appear to limit vegetational development to zones or patches with more diverse plant communities being limited to areas of reduced slope. Colonization of bare spoil continues with *Solidago, Rubus,* and *Andropogon virginicus* being major contributors to devel-

opment of biomass. A distinct disturbed habitat, this abandoned strip mine has provided the stimulus for a variety of studies examining the adaptive mechanisms of vegetational development.

Preliminary bryophyte and vascular flora of the Hog Hollow Seeps, Bath County, Kentucky. JACK R. OUSLEY* and ALLEN C. RISK, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

The Hog Hollow Seeps comprise 70 streamhead swamps located near Cave Run Lake Dam in the Daniel Boone National Forest, Bath County, Kentucky. These wetlands occur at the contact between overlying Quaternary fluvial deposits and Mississippian shales and siltstones. The sites range in area from 10 m^2 to over 1000 m^2. The most abundant woody plants in these wetlands are *Acer rubrum, Nyssa sylvatica, Alnus serrulata, Ilex verticillata, Lindera benzoin,* and *Aronia melanocarpa.* The ground layer is dominated by *Carex atlantica* subsp. *atlantica, C. lurida, C. crinita, C. debilis, Osmunda cinnamomea, O. regalis,* and *Glyceria striata.* Bryophytes are abundant at the sites with *Thuidium delicatulum, Pallavicinia lyellii, Odontoschisma, Plagiomnium ciliare,* and *Sphagnum lescurii* being the most common taxa. The Hog Hollow Seeps contain numerous species uncommon in Kentucky. New state records found during the ongoing study are *Telaranea nematodes, Pleuridium palustre, Aneura maxima,* and *Carex seorsa.* Other uncommon taxa include *Sphagnum magellanicum* and *Eriophorum virginicum.* At two of the sites, a putative *Carex* hybrid (*C. seorsa* × *C. atlantica* subsp. *atlantica*) was discovered. The presence of aborted achenes, nonexserted stamens, and morphological intermediacy of the perigynium beak between that of *C. seorsa* and *C. atlantica* subsp. *atlantica* support the hybrid interpretation.

Taxonomic status of the varieties of starry campion, *Silene stellata* (Caryophyllaceae). LORI A. HEEG* and ROBERT F.C. NACZI, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Starry Campion, *Silene stellata* (Caryophyllaceae), is a perennial herb native to eastern North American deciduous forests. Two varieties have been described for this species: variety *stellata* and variety *scabrella.* Authors disagree regarding the taxonomic merit of var. *scabrella.* Some segregate var. *scabrella* from the glabrous var. *stellata* by the scabrous inflorescences, stems, and leaves of var. *scabrella.* Through studying the morphology, geography, and ecology of *S. stellata* in the laboratory and field, we have tested the hypothesis that variety *scabrella* is a taxonomic entity distinct from *S. stellata.* Statistical analyses of measurements of herbarium specimens (17 characters per specimen) from throughout the range of the species reveal a high level of variability in *S. stellata.* Neither the morphologic characters nor the geographic distribution of *S. stellata* appears to correlate with pubescence patterns. Nearly every population of *S. stellata* we examined contained a mixture of pubescent and glabrous plants. All habitats observed during extensive field work in Kentucky, Virginia, and Tennessee were open, mesic deciduous forests or forest edges. The species occurs in an array of soil types with a broad range of pH values: 3.95–7.63 ($n = 17$ populations). Ecologic data do not indicate a difference in the habitat requirements of the two varieties. Preliminary results indicate that var. *scabrella* should not be recognized at any taxonomic rank.

Vascular flora of Raymond Athey Barrens State Nature Preserve, Kentucky. KERRY L. HALE,* JAMES C. ESTILL, and ZACK E. MURRELL, Department of Biology, Western Kentucky University, Bowling Green, KY 42101.

Raymond Athey Barrens State Nature Preserve, Kentucky, is a site owned by the Commonwealth of Kentucky and managed by the Kentucky State Nature Preserves Commission (KSNPC). This preserve contains some of the best examples of barren communities in the state. The barrens are typified by open-growth post oak and black jack oak dominating the woodland canopy. Cedar glades occur as small openings scattered within the wooded barrens. These habitats support several plant communities and a high diversity of associated species. Several rare or imperiled species have been located in this preserve, such as prairie gentian (*Gentiana puberulenta*), Carolina larkspur (*Delphinium carolinianum*), and upland-privet (*Forestiera ligustrina*). The total vascular flora was inventoried at the 156-acre site from fall 1996 through 1997. Collections were made on a biweekly basis; specimens have been identified and deposited in the WKU herbarium. All data have been entered into the Index Kentuckiensis database to obtain biogeographical and life-history information. Results have been used to determine the number of intrinsic, extrinsic, adventive, and disjunct species present at the site. Biogeographical data were also used to determine relative location and abundance of each species within Kentucky. These results will be used to evaluate the long-term health of the site and to provide data for use as a comparison with other barrens and glades within the karst region.

CELLULAR AND MOLECULAR BIOLOGY

Allosteric regulation of CPSase. AARON HAUBNER* and JEFF DAVIDSON, Department of Microbiology and Immunology, University of Kentucky, Lexington, KY 40506.

In mammals the multi-enzymatic protein CAD initiates the first three steps in de novo pyrimidine biosynthesis. This protein has three separated structural domains each with a distinct enzymatic function. These domains are carbamoyl phosphate synthetase (CPSase), aspartate transcarbamylase (ATCase), and dihydroorotase (DHOase), which represent the first three steps in the pyrimidine biosynthetic pathway. The first is the glutamine-dependent activity of the CPSase domain in which carbamyl

phosphate is produced from bicarbonate, ATP, and ammonia and is driven by the hydrolysis of glutamine. CPSase activity is allosterically inhibited through feedback inhibition by UTP, the end product in the pyrimidine biosynthetic pathway, and is stimulated by 5-phosphoribosy-1-pyrophosphate (PRPP), which is the substrate for the fifth step in pyrimidine synthesis. Previous work has begun to define the region involved in allosteric binding and its importance in CPSase activity. Through a series of replacement and deletion mutations in the region encoding the allosteric site of CPSase an allosterically altered CPSase would be obtained. This altered CPSase may have unique properties in its allosteric regulation. CAD-deficient mammalian cells transfected with the new CAD are to be utilized to obtain the allosterically-altered protein. Through use of a radio-labeled linked enzyme assay, CPSase activity in the presence or absence of varying amounts of UTP and PRPP would be tested. By testing the altered protein activity, the region involved in allosteric regulation CPSase will be better defined.

Analysis of spermatogenesis by a screen for x-linked male-sterile insertional mutations in *Drosophila melanogaster.* BRENT J. PFEIFFER* and JOHN RAWLS, University of Kentucky, Lexington, KY 40506.

The *Drosophila melanogaster* spermatogenesis process is a 10-day program of cellular events directed by a large array of genes. A recent screen in the autosomes has revealed a collection of genes involved in known human defects. We have conducted a similar screen aimed at identifying spermatogenesis genes on the X chromosome of *Drosophila,* using the transposable element P[1wB]. This transposon is distinguishable by the red eye (w+) phenotype and its mobilization is dependent upon the presence of transposase, which will be provided by the element delta, 2-3. Most importantly, genes containing a insertion of the P[1wB] can be easily clone, using features engineered into the transposon. Female flies bearing a Curly (Cy) second chromosome containing P[1wB] by segregation by Cy and w+ among offspring (i.e., w+ non-Cy females); then we tested whether the insertion event of the transposon at a new site has created a mutation affecting spermatogenesis. A total of 232,700 flies were screened, resulting in the isolation of 546 w+ Cy+ females. Segregation analysis showed that 202 of the females bore X chromosome insertions of P[1wB]. Subsequent analysis showed that 14 of these sex-linked mutations are recessive lethals and another 18 are presumptive male-sterile mutations. Further tests are underway to characterize these male-sterile mutations, to identify genes that are involved in the defects and the roles of these genes during spermatogenesis.

Biochemical and functional analyses of the *Neurospora crassa mt a* idiomorph. MELISSA L. PHILLEY,* Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351; CHUCK STABEN, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

The *Neurospora crassa mt a-1* gene encoding the MT a-1 polypeptide determines *a* mating type properties: vegetative incompatibility and sexual mating compatibility with *A* mating type. The in vitro and in vivo functions of the MT a-1 polypeptide and specific mutant derivatives have been characterized. MT a-1 polypeptide produced in *Escherichia coli* bound to specific DNA sequences whose core was 5′-CTTTG-3′. DNA binding was dependent on an intact HMG box domain (a DNA binding domain found in high mobility group proteins and a diverse set of regulatory proteins). Mutations within the HMG box eliminated DNA binding in vitro and eliminated mating in vivo but did not interfere with vegetative incompatibility function in vivo. Conversely, deletion of amino acids 216–220 of MT a-1 eliminated vegetative incompatibility, but it did not affect mating or DNA binding. Deletion of the carboxyl terminal half of MT a-1 eliminated mating and vegetative incompatibility in vivo but not DNA binding in vitro. These results suggest that mating depends upon the ability of MT a-1 polypeptide to bind to and presumably to regulate the activity of specific DNA sequences. However, the separation of vegetative incompatibility from both mating and DNA binding indicates that vegetative incompatibility and mating function by biochemically distinct mechanisms. Preliminary evidence suggests MT a-1 functions as a multimer to control *a*-specific functions.

Do interleukin-6 and glucocorticoids regulate rainbow trout metallothionein gene transcription? JASON HAMMONDS* and CHRISTER HOGSTRAND, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

Metallothionein (MT) is believed a play a role in the redistribution of zinc from plasma to the liver in response to infection and/or tissue injury. MT is a low molecular weight, zinc-binding protein; its synthesis in the liver is increased during stress and infection, apparently to increase the hepatic zinc accumulatory capacity. The 5′-flanking region of the rainbow trout MT-A gene contains putative regulatory elements for glucocorticoids and interleukin-6. Functionality of these cis elements has not yet been illustrated. The purpose of our study is to investigate the roles of glucocorticoids and IL-6 in MT gene transcription activation. A reporter vector system was utilized with different length MT promoters linked to a luciferase reporter gene. One construct contains the putative IL-6 response element, putative glucocorticoid response element, and six metal response elements (pMT-1042). The truncated promoter lacks the IL-6 response element (pGL-6MRE). These constructs are being transfected into salmonid cell (CHSE-214) and transcription activation with IL-6, glucocorticoids and various combinations of the two are ongoing. The inducibility of the rainbow trout MT-A gene by IL-6 and/or glucocorticoids would indicate that MT is involved in the relocation of Zn in an immune and a stress response.

Effects of peroxynitrite on membrane and cytosolic proteins. JENNIFER DRAKE,* TANUJA KOPPAL, LORI BETTENHAUSEN, and D. ALLAN BUTTERFIELD, Department of Chemistry and Center of Membrane Sciences, University of Kentucky, Lexington, KY 40506.

Nitric oxide, a free radical, is very unstable but a relatively benign molecule. However, nitric oxide reacts with superoxide to form a more damaging oxidant, peroxynitrite. Though peroxynitrite is not a free radical, it exhibits hydroxyl radical-like reactivity and indiscriminately attacks all biological components of the cell causing oxidation of proteins, lipids, DNA, and other macromolecules. The goal of our study was to examine damage caused by peroxynitrite to proteins of brain synaptosomal membrane and erythrocyte membranes. Electron paramagnetic resonance (EPR) along with the protein-specific spin label, 2,2,6,6.-tetramethyl-4-maleimidopiperidine-1-oxyl (MAL-6), was used to study the changes in the membrane protein structure. Peroxynitrite was synthesized by bubbling ozone through sodium azide solution and constantly monitoring the absorbance at 302 nm. Initially, time and dose response studies with Mal-6 labeled synaptosomal membrane were conducted. Ten minutes incubation of synaptosomal membrane peroxynitrite caused significant decreases in the W/S ratio, a parameter indicating protein oxidation. Increasing concentrations of peroxynitrite caused increased protein oxidation. Similar trends in the decrease of W/S ratios were observed in erythrocyte membranes. Synaptosomal membrane were then pre-incubated with the antioxidant glutathione before treatment with peroxynitrite, which resulted in protection against protein oxidation. The activity of glutamine synthetase (GS), a cytosolic enzyme highly sensitive to protein oxidation, was also determined after peroxynitrite treatments using the GS Assay. The results of this study showed that 30 minutes incubation of the enzyme with peroxynitrite led to a decrease in GS activity in proportion to increasing peroxynitrite concentration. This study will lead to a better understanding of the damaging role of peroxynitrite in neurodegenerative diseases.

Genetics of a bio-protective alkaloid in grass-endophyte symbioses. ALLISON C. MALLORY,* HEATHER WILKINSON, and C.L. SCHARDL, Department of Plant Pathology, University of Kentucky, Lexington, KY 40546.

Epichloe species and their asexual relatives, *Neotyphodium* spp., are fungal endophytes living in symbiosis with many temperate grasses (subfamily *Pooideae*). In these mutualisms, the fungal symbionts protected their hosts from biotic and abiotic stress factors, while the hosts provide an ecological niche for the symbionts. The biochemical basis for many bioprotectives is several classes of alkaloids. One class, the saturated aminopyrrolizidines "lolines," are of great ecological and agricultural significance because they provide protection from insect herbivores, cause little or no toxicity to grazing mammals, and are hypothesized to play a role in enhanced drought tolerance. Furthermore, these compounds are unique to grass-endophyte associations. Mendelian analysis of loline expression in F_1 and BC_1 generations of *E. festucae* in meadow fescue suggests a single locus (LOL) governs this phenotype. Fingerprints of amplified polymorphic DNA (AFLP) indicated polymorphic bands for the parents that segregated among the progeny. Bands that consistently segregated with lolines expression (<30% recombination) in many progeny will constitute markers closely linked to LOL. Putative markers and those yet to be identified will be used in eventual map-based cloning of the locus. Furthermore, culture conditions have been identified that demonstrate that lolines are fungal metabolites. To date, induction experiments using *N. uncinatum* reveal that lolines expression (1) is qualitatively dependent on nitrogen source and (2) involves similar kinetics across replicates, with maximal expression between 19 and 27 days. Biological materials generated from these induction experiments will be used to further elucidate the genetics and biochemistry of lolines expression.

In vitro translation of random transcripts generated by terminal deoxynucleotidyl transferase. MICHAEL L. SPENCER* and CRAIG TUERK, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

Terminal deoxynucleotidyl transferase (TdT) is a template independent DNA polymerase found in prelymphocytes. TdT is proposed to generate the N region during V(D)J recombination by adding deoxynucleotides to a free 3′ end in a random manner. Here we use TdT to generate a library that encodes for random proteins. TdT was used to extend the oligo T3P in the presence of all four deoxynucleotides. Maximum extensions were obtained in the presence of 0.5 mM dNTP, 2 mM $CoCl_2$, 2 mM BSA, and supplementation of TdT and dNTP at the halfway point of the reaction. We achieved extension lengths of over 1000 nucleotides. The extension product (called dNT3P) was ployC tailed. Another oligo with T7 promoter sequences and polyG tail was annealed to the ployC dNT3P product. Reverse transcriptase was used to fill in the annealed oligos. T7 RNA polymerase was used to transcribe the conversion product followed by treatment with DNase. The resultant RNAs were converted to cDNA using reverse transcriptase and run through 35 cycles of PCR. This step was necessary to eliminate any library products that did not contain a T7 promoter followed by a random region with a fixed 3′ primer annealing site. The library was transcribed using T7 RNA polymerase and translated in vitro to yield a range of random peptides, 30–50 kDa.

Lysophoshatidic acid induces apoptosis in NGF-differentiated PC6 cells. WILLIAM J. FLUKER,* FREDRICK W. HOLTSBERG, and SHELDON M. STEINER, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

Lysophosphatidic acid (LPA) is a novel lipid mediator

with a wide range of biological activities. The brain has high levels of both LPA and its receptor. LPA induces neurite retraction in nerve growth factor (NGF)-differentiated PC12 cells, a tissue culture, neuron model system. The current studies examined LPA-induced responses in NGF-differentiated PC6 cells, a clonal line of PC12 cells. LPA induced apoptosis in PC6 cells within 24 hours as assessed by chromatin condensation and protection with a broad substrate caspase inhibitor, z-VAD-fmk. Associated with apoptosis has been the increase in production of nitric oxide (NO). LPA appears to mediate apoptosis via nitric oxide since nitric oxide synthase inhibitors protect PC6 cells against LPA-induced apoptosis. In contrast to typical LPA signaling, pertussis toxin did not block LPA-induced apoptosis. Activation of signals at the level of gene expression were then examined. NGF-differentiated PC6 cells were treated with LPA and total RNA was collected at various times. Certain mediators such as c-fos and c-jun, that have been induced during apoptosis, are examined by reverse-transcribed polymerase chain reaction (RT-PCR). Further analysis of gene products will continue to determine their role in LPA-mediated apoptosis.

Mechanism for utilization of farnesol and geranylgeraniol for protein isoprenylation in mammalian cells. LONG B. THAI* and CHARLES J. WAECHTER, Department of Biochemistry, University of Kentucky College of Medicine, Lexington, KY 40536.

Research in the Waechter laboratory focuses on the elucidation of how free farnesol (F-OH) and geranylgeraniol (GG-OH) can be utilized for isoprenoid biosynthesis in mammalian cells. When rat C6 glial cells and an African green monkey kidney cell line (CV-1) were incubated with [^{3}H]F-OH, radioactivity was incorporated into cholesterol and isoprenylated proteins. The incorporation of label from [^{3}H]F-OH into cholesterol in C6 and CV-1 cells are blocked by squalestatin 1 (SQ) which specifically inhibits the conversion of farnesyl pyrophosphate (F-P-P) to squalene. This result strongly suggests that cholesterol, and probably isoprenylated proteins, are metabolically labeled via F-P-P. SDS-PAGE analysis of the delipidated protein fractions from C6 and CV-1 cells, revealed several labeled polypeptides. Consistent with these proteins being modified by isoprenylation of cysteine residues, Pronase E digestion released a major labeled product with chromatographic mobility of [^{3}H]farnesylcysteine (F-Cys). A different set of polypeptides was labeled when C6 and CV-1 cells were incubated with [^{3}H]GG-OH. Both sets of proteins appear to be metabolically labeled by [^{3}H]mevalonolactone, and [^{3}H]labeled F-Cys and geranylgeranyl-cysteine (GG-Cys) were liberated from these proteins by Pronase E treatment. *In vitro* experiments are in progress, which use various cell homogenates and possible phosphoryl donors to detect the phosphorylation reactions converting F-OH and GG-OH to F-P-P.

Modulation of synaptic efficacy at the crayfish neuromuscular junction by a molting hormone (20-hydroxyecdysone). MARVIN E. RUFFNER* and ROBIN L. COOPER, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

With quantal analysis of synaptic transmission the evidence presented indicates that the active steroid molting hormone 20-Hydroxyecdysone (20-HE) appears to be acting through a rapid, non-genomic mechanism directly on the motor nerve terminal to decrease the probability of vesicular release in the presence of neural activity during an intermolt stage in crayfish. The quantal analysis reveals that fewer vesicles being released for a given stimulus when 20-HE is present. This reduced synaptic efficacy produces a smaller evoked postsynaptic current which in turn results in a smaller excitatory postsynpatic potential (EPSP) across the muscle fiber membrane. The presented neurophysiological parameters are fitting with the behavior of arthropods (insects and crustaceans) during their molt cycle. This work attempts to demonstrate a presynaptic site of action for ecdysteriods through a non-genomic mechanism in reducing synaptic transmission. The effects of 20-HE can be reversed with application of the crustacean neuromodulator serotonin (5-HT) which enhances synaptic transmission.

Nucleotide variation in isolates of equine infectious anemia virus from donkeys infected with the Wyoming strain. BRAD WILLIAMS,* CHARLES J. ISSEL, and R. FRANK COOK, Department of Veterinary Science, University of Kentucky, Lexington, KY 40506.

Donkeys infected with the Wyoming strain of equine infectious anemia (EIAV) do not exhibit the typical signs of the infection as seen in horses infected with the virus. However, at 18 days post inoculation (dpi) one donkey did become positive for antibody against gp45 of EIAV according to a synthetic antigen ELISA (SA-ELISA). Plasma samples were taken from this donkey at various time points throughout the infection, and presence of the virus was detected by using PCR with primers specifically designed to amplify the 3′ U3 enhancer region of the long terminal repeat (LTR) of the EIAV genome. This region was chosen because it is known to contain transcription factor binding motifs important to viral replication and because it is one of the few hypervariable regions of the EIAV genome. The virus was detected at 210 dpi by first stage PCR. The DNA was isolated and used to produce clones, which were then sequenced. The sequences showed some nucleotide variation compared to the consensus sequence for the Wyoming 3′ LTR. Of these changes, perhaps the most significant was a nucleotide substitution that added a PEA-2 transcription factor binding site. When this same type of study was performed with horses infected with EIAV, all the horses that showed clinical signs of the disease had lost the PEA-2 transcription factor binding motif.

PCR-amplification of the CHD gene allows identification of sex in house sparrows (*Passer domesticus*). EMILY M. HALPIN* and DAVID F. WESTNEAT, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

Under certain environmental conditions, for instance when food is limited, parent birds may vary the sex ratio of their offspring from the expected 1:1. Our understanding of sex ratio evolution is, however, limited by our ability to identify the sex of the offspring at as early an age as possible. In house sparrows, it is impossible to determine the sex nestlings using morphology or behavior. This makes the study of juvenile sex ratio variation very difficult. Using amplification of blood samples, we can now ascertain the sex of nestlings. PCR-amplification and polyacrylamide gel electrophoresis of DNA from house sparrows shows the presence of a unique CHD gene only on the W chromosome. The W chromosome is only present in female birds. Thus, this allows identifying the sex of house sparrows as early as several days after fertilization. Using blood samples from nestling house sparrows then applying this technique, it can now be assessed whether the parent birds are varying the sex ratio of their offspring. The further study of sex ratio variation by parent birds has many implications in the theory of evolution and in species preservation.

Role of Prp38p in spliceosome maturation. ELIZABETH OTTE* and BRIAN RYMOND, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

The spliceosome is a complex enzyme that catalyzes a two-step reaction converting pre-messenger RNA (containing introns) into mature mRNA (lacking introns). The numerous protein and RNA subunits of the spliceosome assemble in a defined order upon each intron substrate. One of the protein subunits of the enzyme in the yeast *Saccharomyces cerevisiae*, Prp38p, was discovered and characterized by the Rymond lab as a factor necessary for pre-mRNA splicing. In the absence of Prp38p, splicing is arrested at a late stage of spliceosome maturation. Based on previous studies, we propose that Prp38p facilitates a conformational change within the spliceosome that permits its essential U6 small nuclear RNA (snRNA) to be properly placed within the active site of the enzyme. It is our hypothesis that Prp38p promotes spliceosome maturation through the release of the U6 snRNA from its intermolecular base pairing with the spliceosomal U4 snRNA. To test this hypothesis, spliceosomes assembled in the presence or absence of Prp38p were purified by affinity chromatography and the state of U4/U6 helices analyzed by gel electrophoresis.

Synaptic activity and the regulation of mouse myosin heave chain IIa. THOMAS E. BELL* and PHILIP H. BONNER, School of Biological Sciences, University of Kentucky, Lexington, KY 40506.

The expression of the mouse muscle protein myosin heavy chain IIa has been shown to be nerve tissue dependent. (Stacey L. Smith, MS. Thesis, UK) This nerve dependency can likely be attributed to either 1) synaptic activity or 2) effects of some trophic factor released from nerve terminals. Satellite cells and fibroblasts derived from postnatal gastrocnemius and soleus muscles were grown in tissue culture and the cells were formed into small tissue-like aggregates. The aggregates were co-cultured with newborn or fetal spinal cord explants. The co-cultures were allowed to incubate for 10-12 days. The muscle fibers in the co-cultures were often contractile and intracellular recording using glass microelectrodes showed the presence of action potentials. Upon addition of curare, contraction and action potentials of active neuromuscular junctions in the co-cultures. These curare-inhibitable fibers were mapped for position and stained by immunocytochemistry using an anti-MyHC IIa monoclonal antibody. Those fibers in which the contractile activity was curare inhibited contained MyHC IIa. Uninnervated mono-cultures showed little or no MyHC IIa. These data suggest a correlation between curare sensitive, synaptic activity and the upregulation of MyHC IIa synthesis.

Synthesis of a cell specific cell-cell cross-linker. CHRISTOPHER J. BORTHS* and BOYD E. HALEY, Department of Chemistry, University of Kentucky, Lexington, KY 40506.

Previous research in this laboratory has shown the existence of a nucleotide binding site on antibodies. This site is in the variable region of both the heavy and light chains at a location of conserved aromatic residues. The binding of a nucleotide, like adenosine triphosphate (ATP), does not diminish the antigen recognition of the antibody. By using the nucleotide binding site as a point of attachment, it is possible to attach a drug to an antibody. This would allow the drug to specifically interact with the cell targeted by the antibody as well as adjacent cells. The synthesis of a nucleotide derivative coupling 8-N_3ATP to ouabain was performed to test the attachment of a drug to an antibody. Once coupled to the antibody, the synthesized nucleotide derivative would allow antigen recognition by the antibody as well as present a biologically active ouabain. The ouabain can bind to the free NA^+/K^+-ATPase of adjacent cells, doing so with a dissociation constant of about 10^{-9} molar, thereby cross-linking two cells. The agglutination of cross-linked cells would then be easily removed from the body. This system provides a means of targeting a specific cell type, like a cancer cell, and removing the cell. The final product has been synthesized but has not yet been fully characterized. It has shown biological activity similar to free ouabain, but NMR and antibody binding studies have not been completed.

CHEMISTRY

Synthesis of a homologous series of N,N′-bis(1-naphthylmethylidene)-alpha,omega-diaminoalkanes. JOHN L. MEISENHEIMER* and NDOFUNSU M. BADIKA,

Department of Chemistry, Eastern Kentucky University, Richmond, KY 40475.

A homologous series of diimines, described as N,N'-bis(1-naphthylmethylidene)-alpha,omega-diaminoalkanes, was prepared to be used in a synthetic sequence that will lead to a variety of new heterocyclic compounds. In the course of determining the nature of these compounds, two interesting physical properties were observed. The melting points vary substantially with respect to an odd or even number of "alkane-type" carbons in the molecule. They follow the usual pattern of relatively higher melting points with an even number of carbons even though this portion of the molecule is only a very small fraction of the total formula weight. The ^{1}H NMR shows only six aromatic hydrogens per naphthyl group in their usual region of absorption, 7-8 ppm units down-field from the TMS reference, rather than the seven hydrogens per naphthyl group that are obviously present. There is, however, an additional proton absorption for two protons further downfield in the region of the anisotropically deshielded hydrogens of the two imine functions. It is our hypothesis that this absorption behavior is a result of an intramolecular association of the number eight hydrogens of the naphthyl groups with the lone-pair electrons on the imine nitrogens. We term this an example of "impositional hydrogen-bonding." We present a computer-generated molecular model that clearly indicates the proximity of the number eight hydrogens of the naphthyl groups to the imine nitrogens.

GEOLOGY

Comparison of land drainage with joint systems. DANIEL S. BRYANT, Department of Physical Sciences, Morehead State University, Morehead, KY 40351.

Segments of meandering streams appear to follow patterns believed to be directly related to systematic jointing. In our field work we used simple techniques: a Brunton compass to find trends of the joints and a protractor to measure trends of segments of the Little Sandy River in locations on the Ashland and Argillite, Kentucky, 7 ½-minute topographic quadrangles. The data were then analyzed to demonstrate that jointing correlates well with the geometry of meandering streams. Joints are generally vertical or nearly vertical planar rock fractures with no appreciable movement. They originate by tensional stress or the release of elastically stored stresses over a given area. Joints occur in sets that are parallel and usually coincide with a set perpendicular or nearly so to each other. If two or more sets of joints occur, then the pattern is referred to as a joint system. This pattern is compared to the changing directions of the meandering stream studied. To obtain data, we located many outcrops in the area and measured the joint directions. Also, the linear segments of the stream were measured on the map with a protractor. Both data sets were plotted on a rose diagram to find four mean directions, each of which was within about 1 degree difference, demonstrating that the part of the Little Sandy River studied appears to be controlled by jointing.

The Kinderhookian-Osage (lower Mississippian) boundary in southeastern Ohio based on conodonts. ARLINDA J. FANNIN* and CHARLES E. MASON, Department of Physical Sciences, Morehead State University, Morehead, KY 40351.

The Kinderhookian-Osagean boundary in southeastern Ohio has been a topic of debate for many years. We sought to locate this boundary by using conodont biostratigraphy. The boundary, in the area of Morehead, Kentucky, has previously been identified using conodonts to occur in the basal 25–50 cm of the Borden Formation. We focused on an equivalent interval found along Ohio route 32 at the Adams and Pike county line. All samples were collected from mudstone intervals within the basal 3 m of the Henley Member of the Cuyahoga Formation. Seven 5-kg samples were processed and examined for conodonts. The first set, three samples, was taken from the basal 10 cm, a 30-cm interval above the dolostone bed, and a 30-cm interval below the first siltstone bed. The 30-cm sample above the dolostone bed contained conodonts from both the uppermost Kinderhook and lowermost Osagean conodont biozones. To locate the boundary more precisely, we took the second set, four samples, at 10-cm intervals above the dolostone bed. The second sample contained elements from both the *Siphonodalla isosticha*-upper *crenulata* zone from the uppermost Kinderhookian and lower *Gnathodus typicus* zone from the lowermost Osagean. Thus the boundary between the Kinderhookian and the Osagean series in southeastern Ohio occurs between 0.56 and 0.66 m above the base of the Henley Member of the Cuyahoga Formation.

Mineral composition of fossil cephalopod hard parts from the lower Mississippian of Kentucky. CODY BLACKBURN,* Department of Physical Sciences, Morehead State University, Morehead, KY 40351; R. THOMAS LIERMAN, Department of Geography and Geology, University of Louisville, Louisville, KY 40251; CHARLES E. MASON, Department of Physical Sciences, Morehead State University, Morehead, KY 40351.

The mineral composition of fossil cephalopod hard parts from the lower Mississippian of Kentucky is believed to be original hard parts (aragonite). Currently the oldest reported original hard parts in the world have come from the lower Pennsylvanian-age Kendrick Shale found in eastern Kentucky. The specimens examined came from two areas. The first was a nautiloid from the Big Hill section, Madison County, Kentucky; the second was an ammonoid from along U.S. 127 just south of Liberty, Casey County, Kentucky. The specimens were collected from the basal part of the Nancy Member of the Borden Formation. The composition of modern cephalopod samples, namely Nautilus, Sepia, and cuttle fish, and inorganic mineral samples of aragonite were used to establish a basis

for comparison. The known samples along with unknown cephalopod samples were crushed with a glass mortar and pestle. The samples were then passed through a small-mesh sieve. After drying they were run through a dry sieve and scattered onto microscope slides painted with nail polish (to hold the small fragments in random orientation). The samples were then run through the X-ray diffractometer to determine their composition. The samples in question were then compared to the known samples. The nautiloid samples from Madison County were determined to be calcite rather than aragonite. However, the ammonoid samples from Casey County showed strong but not conclusive evidence of aragonite.

Mountain bog soils: Kentucky's missing histosols? DEMETRIO P. ZOURARAKIS,* A. (TASOS) KARATHANASIS, and MARC EVANS, Kentucky Division of Conservation, Department for Natural Resources, 663 Teton Trail, Frankfort, KY 40601.

Hearing news of the discovery of previously undocumented bogs in Cumberland and Pine Mountain, we speculated that organic soils, or Histosols, unknown to occur in Kentucky might be present in these unique, relict ecosystems. A visit was organized to bogs within the Cumberland Gap Historic Park, where Sherri's Bog and others were visited. This is a bog complex, large enough to be open to the sun, and characterized by dense mats of mosses and herbaceous vegetation. Unlike most of the bogs, which occur near the heads of drainages (hollows) close to the top of the mountain crest, this relatively large complex occurs in the floodplains adjacent to streams. Woody vegetation ranged from scattered individual shrubs or saplings to rarely dense stands of shrubs, with large trees rarely occurring. Thick cushions of mosses carpet parts of the bog. Typical or characteristic plants, like many sedges and rushes, as well as uncommon or rare plants also exist. Soil profile descriptions and total carbon data of samples taken at two contrasting sites, characterized by the abundance of fern muck and moss peat, respectively, show the predominance of organic horizons in these profiles. The information available thus far gives support to the hypothesis that these are, in fact, previously unclassified soils, representing inclusions in the official Soil Survey of Bell and Harlan counties.

A new Middle Devonian (Givetian) ammonoid fauna from the Boyle Dolomite of central Kentucky. CHARLES E. MASON,* Department of Physical Sciences, Morehead State University, Morehead, KY 40351; GLEN C. BARNETT, 255 Old Flemingsburg Road, Morehead, KY 40351; DAVID M. WORK, Nevada State Museum, Carson City, NV 89701.

The Middle Devonian (Givetian) ammonoids of our study were first discovered as silica-replaced casts in residual soils derived from the Boyle Dolomite in a tobacco field located near the southwest corner of the Hedges 7-1/2′ quadrangle, Clark County, Kentucky. An additional specimen was discovered as float in a nearby stream. The Boyle Dolomite ranges from 5 to 6 feet in this area and is underlain unconformably by the Bisher Dolomite and conformably overlain by the Ohio Shale. It consists predominantly of dolomite and chert with minor interbeds of shale. The Boyle ammonoid fauna includes *Pharciceras* sp. aff., *Pharciceras tridens* (Sandberger), *Pharciceras* n. sp., *Tornoceras* n. sp., and gen. et sp. indet. *Pharciceras* is the dominant element of this fauna in both diversity (two species) and abundance (12 out of 14 specimens). Collectively, these ammonoids indicate reference to the classical *Pharciceras* Stufe of latest Givetian age. This represents the first report of *Pharciceras* sensu strictu in North America and the first reported Devonian ammonoids from Kentucky. *Pharciceras* Stufe faunas containing elements similar or common to the Boyle fauna are known from North Africa, Spain, and Germany.

Paleoecology and taphonomy of a Middle Ordovician edrioasteroid firmground, central Kentucky. B. NICHOLAS GARLAND* and FRANK R. ETTENSOHN, Department of Geological Sciences, University of Kentucky, Lexington, KY 40506.

This paper details the plight of a Middle Ordovician community that was rapidly buried and subsequently fossilized in the Sulphur Well Member of the Lexington Limestone near Danville, Kentucky. Of major concern in this community is a group of extinct echinoderms known as edrioasteroids. These relatively small animals lived as epifaunal filter feeders, primarily on brachiopod valves atop marine firmgrounds and hardgrounds. The edrioasteroid in our study, *Cystaster stellatus*, largely used the shells of the brachiopod *Rafinesquina "alternata"* as its substrate and occurs in such great numbers on this firmground as to enable a study of its paleoecology and taphonomy. The disarticulated, convex-up position of most *Rafinesquina* valves suggests that the valves were transported to the locality, because the living animal is normally bivalved and lives in a convex-down position. *Cystaster stellatus* demonstrates a marked tendency to cluster near the elevated central portion of the brachiopod shells, presumably to elevate themselves higher into the water column. If the brachiopods had been alive at the time, it is more likely that the edrioasteroids would have congregated near the margins of the shells where food-rich waters were being drawn into the shells. This evidence suggests that the edrioasteroids colonized the firmground to gain a feeding advantage shortly after the dead, disarticulated brachiopod shells were transported onto the surface. Edrioasteroids appear to have been relatively fragile animals containing only a few small plates as hardparts. These plates readily dissociated after death, making preservation uncommon. Thus, the fact that so many edrioasteroids are well preserved on this surface indicates that the surface experienced rapid burial by fine-grained sediment. Most likely, the sediment was deposited after an intense storm moved through the area, churning the upper levels of the shallow sea. In the aftermath, the edrioasteroid commu-

nity was left buried. Hence, preservation of this surface allows us to peer for an instant in geological time at the life of a unique and extremely rare sea-bottom community—a Middle Ordovician edrioasteroid firmground.

Range extension of the Kinderhookian age-AA fauna in southeastern Ohio and northeastern Kentucky. RYAN L. WARD* and CHARLES E. MASON, Department of Physical Sciences, Morehead State University, Morehead, KY 40351.

The fauna found in the basal part of the Borden Formation is a dysaerobic fauna of uppermost Kinderhookian age and is composed predominantly of pyrite-replaced juvenile mollusks. Its original discovery was along the AA highway at the Brightman Cemetery section in Lewis County, Kentucky. A recent study has extended its range north to Shawnee State Park in Ohio. Our study determined that the geographic range of this fauna does extend farther than previously known along the strike of its outcrop belt to the northeast and southwest. Three areas were sampled: near the entrance of Shawnee State Park, along Ohio 32 at the Pike and Adams county line, and along I-64 at mile-post 135. After the bulk samples were dried, a 5-kg subsample was extracted for processing. All samples were then soaked in kerosene for 24 hours. The kerosene was decanted and water was added. The samples were then wet-sieved using U.S. standard #20 and #140 nested sieves. The remaining sample was dried, and the material caught on the #20 sieve was examined under a binocular microscope. The Shawnee sample, found earlier to contain the AA Fauna, was used for comparison in this study. The Ohio 32 sample, although weathered, had the AA Fauna in abundance, thus extending the range along strike northeast 20 miles. The I-64 sample, heavily weathered, also contained elements of the AA Fauna, thus extending the range along strike southwest 34 miles. This fauna has now been found to persist 65 miles along strike in the basal 10–12 centimeters of the Henley Bed of the Farmers Member of the Borden Formation.

Retrospective view of Kentucky's 1992 Professional Geologist Registration Act. JOHN C. PHILLEY, Department of Physical Sciences, Morehead State University, Morehead, KY 40351.

After nearly 2 decades of effort, a law was enacted by the Commonwealth of Kentucky in 1992 to provide for the registration of geologists engaging in the public practice of geology. The law provides for a five-member Board of Registration for Professional Geologists, which administers the provisions of the law and serves ca. 2000 registered geologists. The Division of Occupations and Professions within the Department of Administration in the Finance Cabinet provides office space and assistance for the Board. The Board has established various administrative regulations and has adopted the licensing examinations developed and maintained by the National Association of State Boards of Geology. The success of registration candidates on the licensing examinations may have significant implications for assessing the effectiveness of undergraduate degree-granting geology programs.

HEALTH SCIENCE

Effects of dietary energy restriction and exercise on body weight of female rats. DAMON SHARP,* YI ZHANG, and CHANGZHENG WANG, Human Nutrition Program, Community Research Service, Kentucky State University, Frankfort, KY 40601.

To study the combined effects of energy restriction and exercise on body weight reduction, 60 female Fischer 344 rats (7 months old) were randomly assigned into six groups of 10 each in a 2×3 factorial experiment. The control group was fed the control diet (AIN-93M). The R80 and R60 groups were fed the R80 diet and R60 diet at 80% and 60% of the average intake of the control. The R80 and R60 diets provided the same amounts of protein, minerals, and vitamins but only 80% and 60% of the energy consumed by the control. The intake of exercising groups was matched to the corresponding non-exercising groups. The exercise groups were trained to run on a treadmill for 30 min/day, 5 days/week at the speed of 30 m/min. The non-exercising groups were kept in the treadmill without running for the same amount of time. All rats were fed daily and weighed every other day. Body weight of the control group did not change during the 10-week period, but body weights of R80 and R60 groups decreased. Starting at week 4, body weight of the exercising groups became lower than the corresponding non-exercising groups. At the end of the experiment, body weights of R80 and R60 groups were reduced from their initial body weight by 10% and 26%, respectively. Exercise caused additional body weight reduction. Therefore, combining energy restriction and exercise resulted in more weight reduction than energy restriction or exercise alone.

Effects of dietary energy restriction with exercise on bone mineral content and bone mineral density in Fischer 344 rats. YI ZHANG* and CHANGZHENG WANG, Human Nutrition Program, Kentucky State University, Frankfort, KY 40601

We determined the effects of energy restriction with exercise on the skeleton of rats. Sixty female Fischer 344 rats (7 month old) were randomly assigned into six groups of 10 each in a 2 x 3 factorial experiment. The control group was fed the control diet (AIN-93M). The R80 and R60 groups were fed the R80 diet and R60 diet at 80% and 60% of the average intake of the control. The R80 and R60 diets provided the same amounts of protein, minerals and vitamins but only 80% and 60% of the energy consumed by the control. The intake of exercising groups were matched to the corresponding non-exercising groups. The exercise groups were trained to run on a treadmill for 30 min/day, 5 days/week at the speed of 30 m/min. The non-exercising groups were kept in the treadmill without running for the same amount of time. Rats were scanned on a dual-energy X-ray absorptiometer

(DEXA) with both the total body scan mode and the appendicular scan mode at week 0, 5, and 10. Bone mineral content and bone density of the total body, femur bone, and the L2–L5 lumbar vertebrates were similar for the exercising groups compared to the corresponding non-exercising groups. The R80 and R60 groups had lower bone mineral content and bone density than the control group. Our results indicated that energy restriction in both levels resulted in significant bone loss and that exercise did not prevent bone loss under the condition of this study.

Precision of rat bone density measured by dual-energy X-ray absorptiometer. JASMIHN WOODARD,* YI ZHANG, and CHANGZHENG WANG, Human Nutrition Program, Community Research Service, Kentucky State University, Frankfort, KY 40601.

Dual energy X-ray absorptiometer (DEXA) offers a powerful research tool to monitor bone density of animals and human subjects. We determined the precision of bone density determined by DEXA. Twelve female Fischer 344 rats were anesthetized before they were scanned twice each with the small animal total body mode and then the appendicular mode. In the total body mode, a region of interest was defined to measure bone mineral content, bone area, and bone density of the right and left femur. In the appendicular mode, only the right femur was measured for these parameters. Total body tissue mass determined by DEXA was consistently higher than actual body weight of the rats, and the two variables were closely correlated ($r^2 = 0.96$). The repeatability of bone mineral content, bone area, and bone density were 0.82, 0.72, and 0.73 for the total body scan. Measurements on the right and the left femur determined with the total body scan were correlated. Bone density of the right femur measured by the appendicular mode was highly correlated with that determined by the total body scan. These results indicate that DEXA can measure rat bone mineral content, bone area, and bone density with acceptable precision. Only one femur needs to be measured because the similarity between the left and right femur. Bone density of the femur can be determined from total body scan.

MATHEMATICS

Effect of closed lab on retention and achievement in CS1 course. CAROL W. WILSON, Department of Computer Science, Western Kentucky University, Bowling Green, KY 42101.

The CS1 closed laboratory course provides a structured and supervised environment in which beginning programming students have an opportunity for hands-on reinforcement and exploration of the topics being covered in lecture. Spurred by national curriculum recommendations, many schools implemented closed labs for their entry-level classes in the early 1990s. Most research on effectiveness of the closed lab has been anecdotal rather than empirical. We conducted a causal-comparative study with 8 semesters of data to determine if there was a statistically significant difference in achievement and retention between the students who were enrolled in both my lecture and lab sections and the students who were enrolled in only my lecture section. The sample was a sample of convenience: the students enrolled in my classes. The lecture-only control group contained 247 students; the lecture-&-lab treatment group, 115 students. Calculated over all 8 semesters, the retention rate of the lab-&-lecture students was a statistically significant 13.33% higher than the lecture-only students. When achievement was reported as a percentage grade, the lecture-&-lab students scored 1.75% higher than the lecture-only students. This was not statistically significant.

PHYSIOLOGY & BIOCHEMISTRY

Antioxidant activity of resveratrol. D.J. SAXON* and D.T. MAGRANE, Department of Biological and Environmental Sciences, Morehead, KY 40351.

A low-density lipoprotein (LDL)/very low-density lipoprotein (VLDL) fraction was isolated by ultracentrifugation from the plasma of rats maintained on a 5% cholesterol diet. Aliquots of lipoprotein containing 200 μM cholesterol were oxidized for 24 hr at 37°C in the presence of 10 μM $CuSO_4$ in phosphate-buffered saline, pH 7.4, containing either resveratrol or ethanol (control). Lipid peroxide formation was then determined by measuring thiobarbituric acid-reactive substances (TBARS). Antioxidant activity (AOA) was calculated with the following formula: $AOA = (100)(TBARS_{CONTROL} - TBARS_{RESVERATROL})/TBARS_{CONTROL}$. When 1, 5, or 10 μM resveratrol was added at the beginning of the oxidation reaction, the resveratrol inhibited oxidation of the lipoprotein in a dose-dependent manner. The AOA of 10 μM resveratrol was 63%. A delay of 1 hr before the addition of 10 μM resveratrol to the oxidation reaction did not reduce the antioxidant capability of resveratrol, but a delay of 2 hr before the addition of 10 μM resveratrol did reduce the AOA. Pre incubation of 10 μM resveratrol with the lipoprotein for 4 hr before the addition of $CuSO_4$ did not increase the AOA of resveratrol.

Antioxidant effects of tamoxifen. D.T. MAGRANE* and D.J. SAXON, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

Although estrogens have been reported to act as antioxidants, the effect of the estrogen blocker tamoxifen (TAM) on lipoprotein oxidation, has not been studied. A low-density and very low-density lipoprotein fraction was isolated by ultracentrifugation from the plasma of rats maintained on a 5% cholesterol diet. Lipoprotein aliquots containing 200 μg cholesterol were oxidized for up to 24 hr at 37°C in the presence of 10 μM $CuSO_4$ in phosphate-buffered saline, pH 7.4, containing either TAM or ethanol (control). Lipid peroxide formation was then determined by measuring thiobarbituric acid-reactive substances (TBARS). Antioxidant activity (AOA) was calculated with the following formula: $AOA = (100)(TBARS_{CONTROL} - TBARS_{TAMOXIFEN})/TBARS_{CONTROL}$. When 1, 5, or 10 μM

of TAM was added at the beginning of the oxidation reaction, inhibition of lipoprotein oxidation was dose-dependent. The AOA of 10 μM TAM was 70%. If the addition of 10 μM TAM was delayed 1 hr after the oxidation reaction was initiated by Cu^{2+}, the AOA was not reduced when measured at 2 and 4 hours. However, if TAM was delayed 2 hr, lipoprotein oxidation was reduced. Pre-incubation of 10 μM TAM with lipoprotein for 4 hr before the addition of Cu^{2+}, did not increase AOA of TAM.

Effects of glycosylation on functional properties of skeletal muscle and cardiac sodium channels. Y ZHANG,* D. SPECK, and J. SATIN, Department of Physiology, University of Kentucky, Lexington, KY 40536.

The effects of glycosylation on cloned rat skeletal muscle μ1 and human cardiac hH1 Na^+ channels were studied with and without pretreatment of glycosidases in μ1 and hH1 transfected HEK 293 cells using whole-cell and cell-attached patch clamp. In μ1 transfected groups, pretreatment of endoglycosidases castanospermine (100 μg/ml) and swainsonine (500 ng/ml) as well as exoglycosidase neuraminidase (0.15 U/ml) caused significant shifts of $V_{½}$ for steady-state activation to depolarization direction ($\Delta V = \sim 6$ mV). For hH1 groups, castanospermine (100 μg/ml) pretreatment also caused about 6 mV depolarization shift of $V_{½}$ for steady-state activation. For steady-state inactivation, endoglycosidase pretreatment resulted in a small shift of $V_{½}$ to hyperpolarizing direction in μ1, but a big depolarizing shift of $V_{½}$ in hH1. The possible role of charge-screening effect in glycosidase-induced depolarization shift of $V_{½}$ for steady-state activation was investigated with addition of extracellular divalent cation (Mg^{2+}). For μ1 transfected cells, castanospermine pretreatment significantly reduced Mg^{2+} (3~30 mM)—elicited depolarization shift of $V_{½}$ for steady-state activation when compared to the situation in control. These data suggest (1) that glycosylation of μ1 and hH1 sodium channels could regulate cell excitability by differentially altering activation and inactivation kinetics in these two channel isoforms and (2) that the effect of glycosylation on activation behavior is at least partly through charge-screening mechanism. We are testing if treatment of glycosidase could change the gating current, as well as the single channel conductance and opening probability in μ1 and hH1 transfected cells.

Effects of non-mammalian antidiuretic hormone, arginine vasotocin, on developing American bullfrogs, *Rana catesbeiana*. ENDANG L. WIDIASTUTI and JOHN J. JUST,* Department of Biological Sciences, University of Kentucky, Lexington, KY 40506.

When tadpoles are injected with arginine vasotocin (AVT), the body weight increases (a tadpole "Brunn effect"). To understand whether the Brunn effect is caused in part by AVT's action on the mesonephric kidney, 170 tadpoles were cannulated prior to 10^{-5} M AVT injection. Two groups of tadpoles, Taylor-Kollros stage T-K VII–XV and T-K XVI–XIX, treated with AVT had urine formation rates (UFRs) (2.4 ± 0.5 or 6.1 ± 1.2 μl/g/hr) significantly lower than the UFRs of vehicle injected controls (8.9 ± 0.9 or 10.7 ± 1.6 μl/g/hr). Two AVT receptor (V_1 or V_2) antagonists were injected with AVT. Neither antagonist prevents a decrease in UFR caused by AVT (V_1 = 1.9 ± 1.2 μl/g/hr, V_2 = 0.9 ± 0.5 μl/g/hr) in young tadpoles (T-K VII-XV) but both antagonists inhibited the AVT action in older tadpoles (T-K XX–XXV) as indicated by elevated UFRs (V_1 = 13.4 ± 3.8 μl/g/hr, V_2 = 16.0 ± 11.5 μl/g/hr). Thus the mesonephros of older tadpoles has two receptors (V_1 and V_2) for AVT and a third unknown AVT receptor exists in kidneys of the youngest tadpoles. Just like AVT, dehydration of tadpoles also decreases the UFR at all stages. The V_1 and V_2 receptor antagonists do not show the same response in dehydrated tadpoles as they did in AVT injected tadpoles. This suggests that dehydration in tadpoles does not cause a decrease in UFR by only causing a release of AVT from the posterior pituitary but must bring about the decrease in UFR by other hormonal or physiological modulations.

Partial characterization of Na^+,K^+-ATPase and its gill and antennal gland osmoregulatory role in the crayfish, *Orconectes putnami*. M.E. FULTZ* and D.T. MAGRANE, Department of Biological and Environmental Sciences, Morehead, KY 40351.

Crayfish living in a hyposmotic environment excrete copious amounts of very hyposmotic urine. Ionic homeostasis must be maintained by absorption of ions across the gills and reabsorption of ions from the urine by the antennal gland. The enzyme responsible for this absorption is Na^+,K^+-ATPase. *Orconectes putnami* were placed in distilled water, 8.75, 17.5, or 25.5 g NaCl/liter following acclimation to distilled water. Three crayfish were sampled every 2 days. Antennal gland and gill activity as well as Na^+ concentrations in urine and hemolymph were measured. Antennal gland as well as gill Na^+,K^+-ATPase activity decreased as salt in the media increased. In distilled water, urine was very dilute (0.17 mg/ml Na^+ after 10 days) but became more concentrated as the external media concentration increased (4.15 mg/ml in Na^+ after 10 days exposed to 17.5 g/liter NaCl). As the salt concentration increased in the media, hemolymph Na^+ slightly increased from 2.42 mg/ml in distilled water to 3.16 mg/ml in 17.5 g/liter NaCl media. Although *O. Putnami* are able to osmoregulate and tolerate saline conditions, this tolerance was not seen at 5.5 NaCl/liter since all crayfish died within 5 days.

Proliferation and apoptosis in livers of rats receiving tamoxifen and 7,12 dimethylbenzanthracene. J. CARTER,* M. HARTIG, J. ORZALI, A. ARNSPERGER, O. WHITFORD, B. HURST, and D. WARSHAWSKY, Wood Hudson Cancer Research Laboratory, Newport, KY 41071 and Department of Environmental Health, University of Cincinnati, Cincinnati, OH 45267.

Tamoxifen (TAM), a nonsteroidal antiestrogen used to treat breast cancer, may be a breast cancer chemopreventive agent. After oral doses, high levels of TAM are found in livers of women and rats. TAM is a genotoxic hepatocarcinogen in rats. To investigate hepatotoxic effects of TAM and its effects on metabolism of the breast carcinogen 7,12 dimethylbenzanthracene (DMBA), Sprague Dawley female rats were pretreated for 7 days with TAM (0.3 mg/day) then given DMBA (20 mg/rat). TAM treatment continued for 7 days. Some animals were untreated and others received vehicle, or TAM, or DMBA, alone. Apoptosis was detected in histologic sections by the TUNEL method and cell proliferation by immunohistochemical detection of proliferating cell nuclear antigen (PCNA). Relative to untreated controls, treatment with TAM, DMBA, or TAM + DMBA increased the relative liver weight and alkaline phosphatase activity in the liver. TAM reduced the specific activities of cathepsin D and β-glucuronidase. Hepatocyte proliferation and apoptosis were not significantly altered in rats given TAM alone. Apoptosis was significantly increased in livers of rats 1 day after receiving DMBA, and cell proliferation was increased seven-fold 7 days after DMBA. Since DMBA is not a hepatocarcinogen, whereas TAM is hepatocarcinogenic, these data suggest that cell proliferation is not a major risk factor for liver cancer in this model.

Skeletal participation in calcium homeostasis in the adolescent male rat. D.L. DEMOSS* and G.L. WRIGHT, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351; Department of Physiology, Marshall University School of Medicine, Huntington, WV 25704.

Adolescent Sprague Dawley male rats were labeled with 3H tetracycline and fed diets containing various amounts of calcium in an attempt to monitor calcium homeostasis indirectly via bone turnover. Calcium flux from the amorphous/bone fluid compartment and resorption of calcified bone were monitored along with various anatomical parameters (body mass, individual bone mass, 3H-tetracycline content and calcium content) to provide insight into regulation of calcium homeostasis at both skeletal and organ levels. As dietary calcium decreased in concentration from 5% to 0.02%, no effect was observed on body mass, but an independent graduated response was detected for both the bone fluid and calcified compartments. This decreasing calcium-stimulated response initially affected the bone fluid compartment in an attempt to maintain extracellular calcium concentration, but as dietary calcium continued to decrease, calcified bone was called upon to defend plasma calcium levels. Anatomically, the effect of decreasing dietary calcium appears to preferentially affect the appendicular skeleton initially to balance plasma calcium levels and sacrifices bone from the axial skeleton secondarily, and more dramatically only in the face of a severe calcium deficiency.

Tamoxifen inhibits the growth of DU145 human prostate cancer cells in vitro. V. BORUSKE, J. SHERIDAN, M. HARTIG, P. REES,* and J. CARTER, Wood Hudson Cancer Research Laboratory, Newport, KY 41071.

Synthetic estrogens have been used to treat advanced prostate cancer and are thought to reduce testosterone synthesis by suppressing luteinizing hormone-releasing-factor stimulation of the pituitary gland. Evidence has recently been presented that the synthetic estrogen diethylstilbestrol (DES) has a direct cellular effect on several androgen insensitive human prostate cell lines including DU145. DU145 cells were isolated from a brain metastases in a patient with widespread metastatic prostate cancer who was being treated with DES. Growth of DU145 cells was altered when the indicator dye phenol red was absent from the media. Since phenol red has estrogen-like activity on some cultured cells, the antiestrogen tamoxifen (TAM) was tested for growth inhibitory effects on androgen resistant DU145 cells. The immortalized human breast cell line MCF-10F was used as a positive control. Cells were plated in 96 well plates at 1,000 cells per well. After 24 hours the medium was replaced by a medium containing TAM (2.2×10^{-9}–2.2×10^{-4} M). Cell growth was monitored by a non-radioactive cell proliferation assay that utilized bioreduction of the tetrazolium compound MTS (Promega, Madison, WI) as a measure of cell number. Growth was inhibited over 3 days of TAM treatment in a dose dependent manner in both cell lines in the presence of phenol red; however, growth arrest was not associated with apoptosis under these conditions.

PSYCHOLOGY

Individual differences in dysphoria: relations to appraisals, coping, and adjustment. DANIEL R. STRUNK* and EDWARD C. CHANG, Department of Psychology, Northern Kentucky University, Highland Heights, KY 41099.

Previous research has shown that individual differences in dysphoria are significantly linked to global life satisfaction but has yet to consider the potential confounding influence of appraisals and coping activities. Our study attempted to address this issue by examining the influence of dysphoria on appraisals, coping, and global life satisfaction in 361 college students. Results indicated that even after controlling for the potential confounding influence of appraisals and coping, dysphoria remained a significant predictor of global life satisfaction.

SCIENCE EDUCATION

Mandatory environmental education; a case for support. JOHN G. SHIBER, Division of Biological Sciences, University of Kentucky, Prestonsburg Community College, Prestonsburg, KY 41653.

Results of a 2.5-year study of nearly 600 community college students enrolled in five biology courses overwhelmingly (95%) support mandatory environmental education from kindergarten through college. Scores on pre-entry and post-exit tests concerning environmental issues

indicate that biology courses taught with emphasis on the environment increase student environmental awareness by as much as 35% in those with weak backgrounds in biology taking Basic Concepts in Biology and Aspects of Human Biology and by as much as 23% in those with stronger backgrounds taking Human Ecology, Animal Biology, and Conservation Biology. Ninety-six percent of students enrolled in the newly introduced Human Ecology and Conservation Biology expressed enthusiasm for the courses by completing *all* course requirements; 90% became involved in community service and other outside activities appropriate to the course. Further, 59% said they had learned over 75% of the course material; 37% had learned 50% to 75%. Ninety-nine percent would recommend the courses to friends, commenting that the course material enlightened them on the impact of people's activities on the environment and that our environmental problems must be faced and dealt with by all people. Increased public awareness of environmental matters and our responsibility to nature has opened many career possibilities. It would be unfortunate if educators did not seize this opportunity to create standardized courses on the environment as they have for math, English, and other disciplines from kindergarten through college. Such basic training would help prepare students for the immense task of restoring and maintaining our planet's health.

ZOOLOGY & ENTOMOLOGY

Altered protein composition of *Lirceus lineatus* (Isopoda) infected by *Acanthocephalus dirus*. DAVID F. OETINGER, Department of Biology, Kentucky Wesleyan College, Owensboro, KY 42302.

Lirceus lineatus (Say, 1818) collected from Rhodes Creek, Daviess County, Kentucky, have a high prevalence (23.8%) of infection with *Acanthocephalus dirus*. Infected isopods have either lighter integumental pigmentation or are more darkly pigmented; only 0.7% of normally pigmented isopods are infected with *A. dirus*. Previous studies have demonstrated that the affected integumental pigments are tryptophan metabolites in the ommochrome pathway (xanthommatin and ommins). Our study was undertaken to evaluate protein composition of male and female uninfected *L. lineatus*, male *A. dirus*-infected isopods, and female *A. dirus*-infected isopods. Denaturing sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) of homogenized uninfected isopods (excluding the digestive tract) showed that male and female isopods have several weak protein bands, at least one of which (100 kDa) corresponds to that of a hemocyanin. Uninfected female isopods, with brood pouches, had many more protein fractions—12, six of which are in the range of 70 to 130 kDa. Homogenates of lighter-pigmented infected isopods were represented by seven protein bands whereas those of darker-pigmented infected isopods only had one or two protein bands. Homogenates of both male and female *A. dirus* produced 12 distinct protein bands. These results support the hypothesis that the stress associated with reproduction (female isopods with brood pouches) or infection with *A. dirus* have a significant impact on protein metabolism. Results for lighter-pigmented infected isopods are consistent with the concept of nutritional pigmentation dystrophy; whereas results for darker-pigmented infected isopods are similar to what has been reported for ommochrome-pigmented insects that have been subjected to stress.

Comparison of growth and feeding patterns in two species of cave adapted isopod crustaceans (Family Cirolanidae): *Anopsilana crenata* from Grand Cayman Island and *Bahalana geracei* from San Salvador Island, Bahamas. ERIC HOEL* and JERRY H. CARPENTER, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Specimens of *Anopsilana crenata* Bowman and Franz, 1982, were collected from West Bay Cave, Grand Cayman Island; they live in this small cave partially exposed to sunlight and are partially cave adapted with small rudimentary white eyes and slight amounts of reddish brown body pigment. *Bahalana geracei* Carpenter, 1981, were collected from Lighthouse Cave, San Salvador Island, Bahamas; they are highly cave adapted with total loss of eyes and body pigment. Both species were studied in laboratory cultures maintained at 26°C for 4 months to compare growth and feeding rates. *Anopsilana crenata* specimens fed much more frequently (every 2 weeks) compared to *B. geracei* (every 2 months). *Anopsilana crenata* molted much more frequently (every month), compared to *B. geracei* (once a year). *Anopsilana crenata* had no observed premolt fast, while *B. geracei* had an observed 3 to 4 week premolt fast. The activity level was much greater in *A. crenata*, and the life span appears to be much shorter (1–2 years) compared to *B. geracei* (20+ years).

Comparison of movement patterns in male and female *Bahalana geracei*, a marine cave isopod (Family Cirolanidae) from San Salvador Island, Bahamas. RONALD D. BITNER* and JERRY H. CARPENTER, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Bahalana geracei Carpenter, 1981, is a cave-adapted cirolanid isopod crustacean known only from San Salvador Island, Bahamas. Preliminary research showed that males of *B. geracei* are less than 20% of the adult population. We hypothesized that this was at least partially due to males moving more, which would increase their vulnerability to predation and reduce their numbers. Forty-seven freshly captured specimens were placed in individual cubicles, subdivided into 16 squares. Observations on their positions were recorded three to eight times per day for 7 days. Using means and standard errors, we statistically compared the total number of times males and females moved. Males did move more often than females of comparable size, and large females moved more often than small females. These data support our hypothesis that males move more often than females.

Detection of hybridization events between the coyote, *Canis latrans,* and the domestic dog, *Canis familiaris,* using two polymorphic microsatellite loci and cranial morphometric analysis. JOHN J. COX* and CRAIG TUERK, Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

Cranial morphometric and genetic DNA microsatellite analyses were utilized to determine the taxonomic status of the coyote in Kentucky and to detect any potential hybridization between the coyote, *Canis latrans,* and the domestic dog, Canis familiaris. Cranial morphometric analysis involved the employment of 19 linear cranial measurements, previously found to be discriminatory between wild and domestic canids, in a discriminant function analysis. We analyzed 174 canid skulls from the United States and Canada and subsequently used the data to classify 65 unknown canids from Kentucky. Discriminant function analysis indicated hybridization between coyotes and domestic dogs to be 7–11%. However, only one of 28 (3.5%) wild samples indicated hybridization; thus possible overestimation of hybridization may incurred by a potential bias of hybrid sample retention found in institutional collections. DNA samples were taken from 55 Kentucky canids (31 coyotes and 24 domestic dogs). Genetic analysis involved the examination of two microsatellite loci previously determined to be polymorphic. Data indicated a high degree of polymorphism and interspecific allele overlap at one microsatellite locus and distinct species-specific alleles at the second locus, thus indicating the utility of this locus for hybridization assessment. Four individual coyote-like canids shared one allele with domestic dogs at this locus, but hybridization was not confirmed by morphological data. Therefore, on the basis of morphological and genetic data, the Kentucky canids analyzed in this study are best described as *Canis latrans,* the coyote.

Effects of omentectomy on ectopic *Moniliformis moniliformis.* ANGELO M. STERGIOU* and DAVID F. OETINGER, Department of Biology, Kentucky Wesleyan College, Owensboro, KY 42302.

We undertook an experiment to further evaluate the occurrence of a gravid adult female *Moniliformis moniliformis* in the greater omentum of a female laboratory rat, *Rattus norvegicus.* This rat had received orally-administered *M. moniliformis* cystacanths, which should have resulted in lumen-dwelling intestinal parasites. The present experiment sought to determine the fate of intraperitoneally-implanted *M. moniliformis* in omentectomized rats and non-omentectomized rats. In almost all cases, masses with worms were found in apparently-regenerated omental tissue upon necropsy. Usually, the proboscis was free from the omental tissue and the parasites appeared active. In non-regenerated omental tissues, the parasites were found encysted at the pancreas, spleen, or pelvic region. Blood glucose determinations (Boehringer Mannheim "Accu-Check") of omentectomized-infected hosts supported the hypothesis that intraperitoneal *M. moniliformis* does bring about decreased blood glucose levels. Glucose levels declined to as low as 85 mg/dl for an omentectomized-infected rat at 105 days post infection. Glucose levels of the omentectomized-infected rats decreased rapidly perhaps because of increased pancreatic activity. Also, in an omentectomized-infected rat with a glucose level of 85 mg/dl at 105 days post infection, *M. moniliformis* was found to be interwoven among pancreatic tissue at necropsy. This finding is consistent with the observation that there appears to be hypertrophy of pancreatic tissue.

Hypoxia: a stimulus for age-dependent induced hatching of the walleye, *Stizostedion vitreum.* SARAH M. BLANK,* JEFF WEAVER, and JOHN J. JUST, Department of Biological Sciences, University of Kentucky, Lexington, KY 40506.

Most aquatic embryos grow inside a proteinaceous egg case from which they must escape to complete development. Oxygen (O_2) consumption increases during embryonic development while surface area for gas exchange remains constant; thus hypoxia may be a natural stimulant for the release of hatching enzymes. A repeated measures experiment was utilized to examine hypoxia as a stimulant of hatching. Embryos 6–20 days post-fertilization (PF) and raised at 10–12°C were exposed to nitrogen (0% O_2), air (20% O_2), oxygen (100% O_2), and a mixture of air and nitrogen (10% O_2); percent hatch was recorded at 10-minute intervals for 90 minutes. A minimum of four experimental units consisting of 15 embryos in a 50 ml vial containing 10 ml of pond water was used for each treatment at each developmental time period. Control embryos first hatch on day 17 PF reaching 5% hatch with 100% hatch occurring on day 21 PF. Hypoxia (10% O_2) induced premature hatching on day 18 PF as the percent hatch of those embryos exposed to environments of 10% oxygen, 20% oxygen, and 100% oxygen was 67%, 54%, and 13%, respectively. Percent induced hatching increased in an age-dependent fashion as demonstrated by comparing day 18 PF (above) to day 19 PF embryos exposed to the same three oxygen environments (10, 20, or 100%) resulting in 92%, 57%, and 23% hatch, respectively. Walleye embryos were sensitive to anoxia. Exposure of day 18 and 19 post-fertilized embryos to anoxia for 40 minutes and 60 minutes resulted in 33% and 100% mortality, respectively, within 24 hours. Hyperoxia (100% O_2) delayed hatching for at least 3 hours in 18-, 19-, and 20-day post-fertilized embryos.

Role of male chemosignals in female odor- and social-preferences in prairie voles. JENNIFER L. WILES* and TERRY L. DERTING, Department of Biological Sciences, Murray State University, Murray, KY 42071.

Female prairie voles must be exposed to chemosignals of conspecific males to be reproductively active. Upon activation, female voles use olfactory cues to choose a mate. The level of testosterone in a male prairie vole has been associated with female preference for male odor. Testosterone level in male prairie voles, and consequently fe-

male odor preferences, may be affected by physiological condition. We studied the effect of testosterone level and nutritional history on attractiveness of male odors to females, and female odor, social, and mate preferences. The odors of males born to mothers food-deprived during pregnancy were preferred by more females than were the odors of males born to mothers fed ad libitum. Maternal food-deprivation did not significantly affect the body mass, survival, or plasma testosterone level of male offspring. The odors of males food-deprived post-weaning were not more attractive to females than the odors of control males. Females spent a greater amount of time investigating the odors of males with a high testosterone level, regardless of whether the males were control or food-deprived post-weaning. Level of plasma testosterone and the nutritional history of males can influence the attractiveness of male odors to females, but female odor preferences are not always indicative of female social and mate preferences.

Status survey of the endangered duskytail darter, *Etheostoma percnurum,* in Big South Fork of the Cumberland River, Kentucky. BROOKS M. BURR and DAVID J. EISENHOUR,* Department of Zoology, Southern Illinois University, Carbondale, IL 62901; Department of Biological and Environmental Sciences, Morehead State University, Morehead, KY 40351.

From 7 to 9 Sep 1995, an intensive survey of a 19 km reach of the Big South Fork of the Cumberland River was conducted with the goal of finding the federally endangered duskytail darter, *Etheostoma percnurum,* in Kentucky. Using underwater observation and kick-seining around slabrocks, we found 60 specimens. The primary habitat of *E. percnurum* includes clean, silt-free rocky pools immediately above riffles, where it seeks cover under cobbles and slabrocks. Five of eight sites we sampled produced at least one *E. percnurum,* with the greatest abundance near the mouth of Troublesome Creek. The range of this species in Kentucky is confined to 7 stream km of the Big South Fork; this darter was the rarest of the 12 darter species we encountered. We recommend that *E. percnurum* be added to Kentucky's list of protected species as an endangered species. A preliminary morphological comparison of specimens from the Big South Fork (Cumberland River drainage) and Copper Creek (Tennessee River drainage) revealed strong differences in aspects of squamation and body shape. Our comparative analyses suggest that populations of Big South Fork *E. percnurum* constitute an independent evolutionary unit. However, sample sizes are small. We strongly recommend an additional search for the species in spring to obtain nuptial males and females and to observe the species' nesting biology.

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1. GENERAL

A. Original papers based on research/review in science will be considered for publication in the *Journal*; at least the first author must be a member of the Academy. Announcements, news, and notes will be included as received.

B. Papers (in triplicate) may be submitted at any time to the editor.

John W. Thieret
Biological Sciences
Northern Kentucky University
Highland Heights, KY 41099
Phone: (606) 572-6390
FAX: (606) 572-5639
E-mail: thieretj@nku.edu

List in the cover letter your telephone/FAX numbers, your E-mail address, and the names, addresses, and phone numbers of two persons who are potential reviewers.

C. Format/style of papers must conform to practices in recent issues of the *Journal*, which are, in effect, a style manual. The running head at top right of each page should give name of author(s), a short version of paper title, and page number of total. Do not staple pages together.

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C. Sequence of sections in papers should, where appropriate, be as follows: title of paper, name/address of author(s), abstract, body of paper, footnotes, table captions, figure captions (all the preceding on consecutively numbered pages), tables, and figures.

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E. The abstract, not to exceed 200 words, should be concise, descriptive, and complete in itself without reference to the paper.

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D. Names of authors of binomials may be included but only at the first mention of the binomial. Cultivar names are not italicized but are enclosed in single quotes or preceded by cv.

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Lacki, M.J. 1994. Metal concentrations in guano from a gray bat summer roost. Transactions of the Kentucky Academy of Science 55:124–126.

BOOK

Ware, M., and R.W. Tare. 1991. Plains life and love. Pioneer Press, Crete, WY.

PART OF A BOOK

Kohn, J.R. 1993. Pinaceae. Pages 32–50 in J.F. Nadel (ed). Flora of the Black Mountains. University of Northwestern South Dakota Press, Utopia, SD.

WORK IN PRESS

Groves, S.J., I.V. Woodland, and G.H. Tobosa. n.d. Deserts of Trans-Pecos Texas. 2nd ed. Ocotillo Press, Yucca City, TX.

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Each table and its caption must be double-spaced, numbered in Arabic numerals, and set on a sheet separate from the text. The caption should begin with a title relating the table to the paper of which it is a part; it should be informative of the table's contents. Statistics presented in the table should be explained in the caption (e.g., means are presented $\pm$ SE, $n = 7$). Table should be submitted in hard copy only; they need not be included on the disk.

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NEWS

The 1998 annual meeting of the Kentucky Academy of Science will be held November 12, 13, and 14 at Jefferson Community College, Southwest Campus, Louisville.

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ARTICLES

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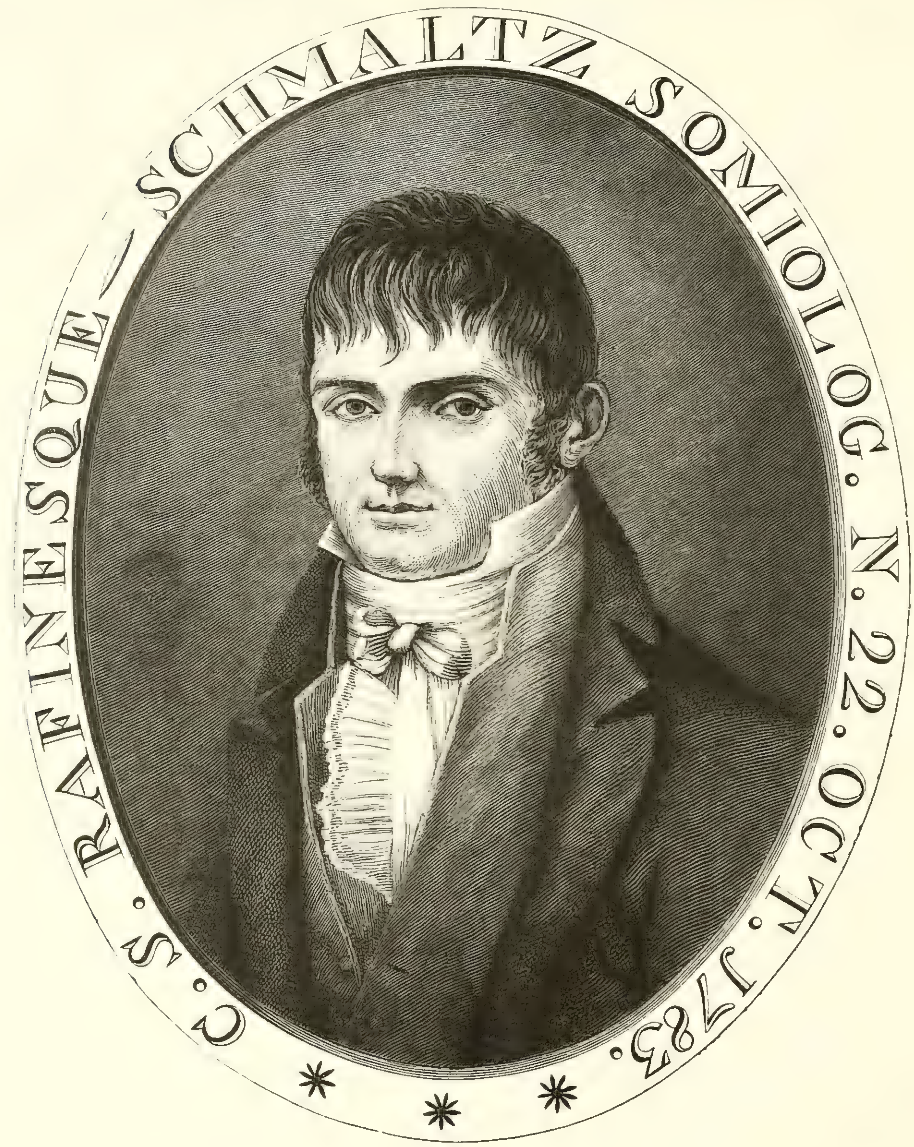
Special Paper

Rafinesque's Botanical Pursuits in the Ohio Valley (1818–1826)

Ronald L. Stuckey

Herbarium, Museum of Biological Diversity, Department of Plant Biology, College of Biological Sciences, The Ohio State University, 1315 Kinnear Road, Columbus, Ohio 43212



CONSTANTINE SAMUEL RAFINESQUE.

Figure 1. Portrait of C. S. Rafinesque drawn from life by the artist Falopi in 1810, when Rafinesque was age 27. Reproduced from Youmans (1896, opposite p. 182).

INTRODUCTION

Although Constantine Samuel Rafinesque (1783–1840) (Figure 1) published papers and books in many disciplines within the sciences and humanities, his favorite pursuit and most extensive scientific work was in botany. His botanical contributions are the ones that have been most thoroughly scrutinized and evaluated by his contemporaries and their successors. In these analyses, Rafinesque is most often criticized for having seen too much variation in plants, a propensity that led him to provide generic, specific, or varietal names for minor variants. His formal descriptions of new plants were often cryptic and incomplete as judged by his reviewers and by today's standards. For example, he did not always make adequate comparisons of critical morphological structures of leaves, flowers, and fruits with those of closely related taxa, nor did he always provide information on habitats, geographical locations, and donors or collectors of specimens with the completeness preferred by present-day botanists.

The most damaging review of Rafinesque's taxonomic botanical publications was written by the young, talented Asa Gray (1810–1888), who was to become North America's foremost botanist during the second third of the century. The negative comments by Gray (1841) overshadowed whatever credibility Rafinesque's works may have had, to the extent that later taxonomic botanists, who were dominated by Gray's thinking, mostly ignored and forgot Rafinesque's contributions for nearly a century. Yet, Gray did point out that Rafinesque had possessed great potential as a botanist even though he was not well educated in taxonomic and structural botany. Rafinesque had taught himself botany, a study that began when, as a boy in France, he collected plants in the field, pressed them to make an herbarium, and studied Latin in order to read botanical books. Gray admitted that many of Rafinesque's publications were credible contributions and contained new plant names that should have been adopted. Moreover, at that time and for many years later, no plant taxonomist had the knowledge or resources to sort through Rafinesque's new names to determine which were validly published or had priority. The science of taxonomic botany and its code of nomenclature had not yet developed the sophistication to assimilate the mass of information that Rafinesque had added to the literature.

Gray observed that the quality of Rafinesque's work deteriorated from about 1819 to the end of his life in 1840. This gradual deterioration appears to have had its beginning with a series of unfortunate events in Rafinesque's life. The earliest of these occurred on his return trip to North America in 1815, when his ship sank off Long Island, New York, and all of his botanical manuscripts, specimens, and personal possessions were lost to the sea. The effects of this loss may well have been compounded by the rejection for publication of manuscripts that he had submitted to the Committee on Publication at the Academy of Natural Sciences of Philadelphia, and, beginning in 1819, by Benjamin Silliman, the editor of the *American Journal of Science and Arts* (Anonymous 1817–1818; Stuckey 1986; Boewe 1987a). During this same period, Rafinesque learned that the woman with whom he had lived and had two children in Sicily had married a comedic actor soon after his departure from that island. At about the time Rafinesque was becoming established in Lexington, Kentucky, the death of his closest friend and chief benefactor, John D. Clifford (1779–1820), deprived him of an anticipated collaborator on several natural history projects (Pennell 1942). Of his personal sense of loss, Rafinesque wrote to botanist Charles W. Short on 15 June 1820:

> You have heard of the loss of Mr. Clifford [on 8 May], it has been a heavy one for us all, and for me in particular. All the plans we had formed for the benefit of science are nearly defeated. But I shall endeavor to do what I can by myself.

Among the earliest authoritative studies, based on original research, of Rafinesque's life and botanical work were the paper by Gray (1841) and books by Call (1895) and Fitzpatrick (1911). Beginning in the second quarter of the 20th century, the resurgence of interest in Rafinesque's life and scientific work was

marked by detailed critical evaluations of his contributions to taxonomic botany (Fernald 1932, 1944a, 1944b, 1946; Merrill 1942, 1943, 1948a, 1948b, 1949; Pennell 1942; Stuckey 1971a, 1971b, 1986) and by an emended version of Fitzpatrick (1911) by historian Charles Boewe (1982). Thus, it would appear now that little if any evaluation remains to be done from a botanical perspective. The point does need to be made, however, that for the most part these earlier evaluations were concerned primarily with the taxonomic aspects of Rafinesque's botanical work, and although taxonomy was important to him and to the botanical community, Rafinesque did much more than collect, name, and describe new plants.

This paper presents the first comprehensive review of Rafinesque's botanical activities and contributions while he was traveling and conducting field work in the Ohio Valley from 1818 to 1826. The temporal delimitations coincide with the beginnings of botanical exploration west of the Allegheny Mountains, and the geographical region covered, the Ohio Valley, encompasses the lands drained by the Ohio River and its tributary streams. Not discussed in this paper are Rafinesque's original ideas on plant evolution, or what he called "perpetual mutability," his approaches to a natural system of classification of plants, already being developed by the French botanists Antoine de Jussieu (1748–1836) and Augustin Pyramus DeCandolle (1778–1841), and his logical rules that he believed should be used in assigning scientific names to plants. Most of these topics have been considered in some detail by other recent evaluators (Sterling 1978; Porter 1986; Cain 1990). Furthermore, no appraisal is made here of Rafinesque's lengthy and trenchant reviews, published between 1817 and 1819,[237,241,256,258,264,265,267,288,305] of the book-length manuals and floras of various parts of North America.

PREVIOUS EVALUATIONS OF RAFINESQUE'S WORK

Several of the general evaluations mentioned earlier refer to Rafinesque's taxonomic botanical work in the Ohio Valley. The book-length biography by Call (1895) devoted 10 pages to several positive and negative aspects of Rafinesque's work, but he confined his evaluation to Rafinesque's studies of taxonomic botany in the broad sense. Call concluded that Rafinesque's "botanical work demonstrates that he was the creature of an unfortunate environment, the victim of an unbalanced training, the intellectual scientific problem of his day." Pennell (1942) summarized by writing:

> On coming to Kentucky he simply reveled in seeing and describing a new world of living things. He rushed from one group of plants or animals to another in an ecstasy of discovery. He could scarcely spare the precious time for thorough work, and the tedium of minute dissections always irked him. Hence it is that so many of his presentations remain unsatisfactory.

In a more specific analysis, Friesner (1952, 1953) discussed the bearing of Rafinesque's contributions to the vascular plants of Indiana and determined that of the 22 names that Rafinesque proposed for those taxa occurring in Indiana, only *Oenothera pilosella* was currently in use. This statistic alone does not speak well for Rafinesque's powers of discrimination as a taxonomist. Meijer (1973) considered Rafinesque

> a very perceptive enthusiastic worker . . . active at the frontier of the western penetration . . . [who] grossly overestimated the amount of novelties in the Flora of Kentucky compared with the far better explored states of New England and Pennsylvania, though he realized that as far as the trees and shrubs were concerned you could see in Kentucky 'nearly all the trees and shrubs of Virginia, Ohio and Tennessee'; . . . he was a great example of an enthusiastic field worker, a good naturalist, living in a time and surroundings where a pursuit of scientific inquiry for its own sake was a rather rare phenomenon.

CONTRIBUTIONS PRIOR TO COMING TO THE OHIO VALLEY

Rafinesque came from France to Philadelphia in April 1802 and began to study the flora of the east coast of the United States from Virginia to New York and as far west as the Allegheny Mountains in Pennsylvania. Yet, at 21 years of age, he longed for a wider botanical experience. To United States President Thomas Jefferson, Rafinesque (1804) wrote on 27 November 1804, as published by Betts (1944):

> The Western parts of the U[nited]. S[tates]. are as yet very little known. I intend to go and explore part of Kentucky & Ohio next Spring. I wish I could go still farther and across the Mississippi into the unex-

plored region of Louisiana, but it is a mere impossibility in my private Capacity to visit such unsettled and as yet very wild Country .... If it ever seems worthwhile to you, to send a Botanist in Company with the parties you propose to make [a] visit [to] the Arkansas or other Rivers, I can not forbear Mentioning that I would think myself highly honored with the choice of being selected to make known the Veget[abl]e. and Animal riches of such a New Country and would think that Glory fully adequate to compensate the dangers and difficulties to encounter.

Jefferson replied on 15 December 1804 that he was contemplating sending an exploring party to the sources of the Red and Arkansas rivers the following spring. He offered Rafinesque the opportunity to accompany the expedition, but, as Rafinesque had already sailed for Italy and would be living in Palermo, Sicily, for the next 10 years, this first chance to explore the western country did not materialize.

In 1806, while in Sicily, Rafinesque began to send short botanical papers to the *Medical Repository,* published in New York City by his friend Samuel L. Mitchill, M.D. (1764–1831). Among these contributions to North American botany were additions to Andre Michaux's *Flora* (1803),[5] a prospectus of projected botanical works,[8] notes on new genera and species,[9] writings on medicinal properties of selected plants,[10] and a short review of the progress of American botany.[19] Aside from these more routine kinds of notes, Rafinesque published two pioneering papers in North American botany. The first was his admirable "Essay on the exotic plants, mostly European, which have been naturalized, and now grow spontaneously in the Middle States of North America" (1811).[21] This paper was the first on the invasion of foreign plant species onto this continent. Thoroughly researched, it is an excellent review of its subject, drawing information from the writings of the botanists Henry Muhlenberg, Benjamin S. Barton, and André Michaux, from unpublished data from his botanical friends, and from his own knowledge based on three seasons of field work from 1802 through 1804. He provided the scientific names of over 250 species and their sources of invasion, whether by agriculture or gardening or by accident, and he noted their localities, habitats, and abundance. He urged that other writers make distinctions between native and foreign plants and engage in specific studies of invasive species. At the time, Rafinesque was the only botanist in America who had extensive field knowledge of the floras of both North America and Europe. Certainly he was the only one in a position to prepare this innovative treatment.

The second of Rafinesque's pioneering efforts, also published in 1811, was his last paper[22] in the *Medical Repository* and represented in its simplest form a taxonomic revision of two genera of submersed aquatic plants, *Callitriche* and *Potamogeton.* Fundamentally, a taxonomic revision evaluates the studies of the recognized species in a part or all of a particular genus, and it includes the names and descriptions of previously known species, lists synonyms, and provides the names and descriptions of new species. Rafinesque's paper is the first taxonomic revision of a group of plants known to have been published in the United States (Stuckey 1998).

Providing diagnostic characters in Latin and with information on localities for most of the species, Rafinesque's treatment of *Callitriche* enumerated 10 species, from North America and Europe, of which four were new. Of the new ones, he named and described three, and to the fourth he gave a name based on a description from a manuscript by Muhlenberg. He renamed four species and retained the original names for two, citing the original authors. In *Callitriche* it appears that only one of his proposed names, *C. terrestris* Raf., is in use today, but this genus is in need of a critical taxonomic study. Of the eight species of *Potamogeton* that he presented, Rafinesque described two as new, renamed five, and retained one name. Today, *Potamogeton* is a well-studied genus, and four of Rafinesque's seven names are retained at either the specific or varietal level in the flora of eastern North America. One name, *P. petiolaris,* remains to be evaluated.

In 1814, Rafinesque published at his own expense in Palermo his *Précis des découvertes et travaux somiologiques entre 1800 et 1814,*[230] in which he named and described as new to science 38 species of vascular plants. The descriptions included habitat and geographical location, with 17 of the plants being from various parts of eastern North America, 18 from the island of Sicily, and 3 not identified as to geographical source. Of the species from

North America, all were from states bordering the Atlantic Ocean, except one from Canada and another one noted as "In the state of Ohio in N[orth] A[merica]." The latter was a species of spiderwort that Rafinesque called *Tradescantia ohiensis*; it was apparently the first plant that he named from the Ohio Valley. Yet he had not made any journeys to that part of the continent. How then did Rafinesque obtain this specimen?

In the second volume of his *New Flora of North America* (1837, p. 84),[868] published some 20 years later, Rafinesque revealed the source of his Ohio spiderwort, with the statement: "In Ohio . . . described in 1814 from a specimen of Dencke given me by Van Vleck, but I have not met it in Ohio . . . . " Denke, spelled with a "c" by Rafinesque, refers to the Moravian clergyman Christian Frederick Denke (1775–1838), who was a missionary in western Ontario, Canada (Stuckey and Wehrmeister 1979). During the first decade of the 19th century, Denke had studied with the missionary David Zeisberger (1721–1808) at Goshen, Ohio, and served a short time as a missionary to Indians on the Huron River in northern Ohio. John Van Vleck (1751–1831), another Moravian clergyman, resided in Bethlehem, Pennsylvania, where Rafinesque visited him in 1804, at which time he may have given Rafinesque the specimen (Barnhart 1921). The subsequent North American botanical literature referred this species to *T. canaliculata*, named by Rafinesque in the *Atlantic Journal* in 1832,[729] until Fernald (1944b) pointed out that the correct name, based on priority, was *T. ohiensis* Raf.

EXTENT OF TRAVELS IN THE OHIO VALLEY AND ENTHUSIASM FOR FIELD STUDY

In the Ohio Valley, Rafinesque showed considerable enthusiasm for studying plants in the field and published extensively, naming and describing many plants as new to science. However, only a few of his names have priority and are in use today. Rafinesque interacted directly or through correspondence with nearly every known botanist in the Ohio Valley, and he developed an extensive herbarium of western plants by acquisition and exchange with these and other botanists and by his own extensive field collections. His publications on the botany of Kentucky provided the first flora or checklist of plants from the state, the first outline of the state's major phytogeographical regions, and the first discussion of ecological succession of plants in the limestone region of central Kentucky. Beginning in 1819, Rafinesque served as Professor of Botany and Natural History at Transylvania University in Lexington, where he presented lectures on these and other subjects by subscription to ladies and gentlemen of the community. Later, he was also the University's librarian and an organizer and superintendent of the short-lived Botanical Garden. He was instrumental in organizing the Kentucky Institute and presented several lectures before that group.

From his travels and experiences with plants, Rafinesque developed extensive knowledge of the botany of the Ohio Valley (1818–1826). His botanical work at this time is summarized largely from his *Life of Travels* (1836)[863] and his letters to two botanists, Zaccheus Collins (1764–1831) of Philadelphia (Pennell 1942) and Charles W. Short (1794–1863) of Kentucky (Perkins 1938). Rafinesque journeyed by various conveyances—on foot, by covered flatboat, by keelboat on the Ohio River, by coach, by common wagon, and by horse—in company with other botanists and guides. In 1818, at age 34, during his first trip west of the Allegheny Mountains, Rafinesque stopped to search for plants at many of the towns along the Ohio River; among these were Steubenville, Wheeling, Marietta, Gallipolis, Cincinnati, Louisville, and Henderson. From this last place, he then traveled 40 miles to the north, to New Harmony on the Wabash River, where he entered the prairies of Illinois. In the *Life of Travels*,[863] he claimed to have made "a rapid excursion to the mouth of the Ohio," but this locality was actually the mouth of the Wabash, as clarified from Rafinesque's journal by Charles Boewe (pers. comm. 1997). He did not explore along the Mississippi River or go into Missouri as had been his intention. Traveling mostly on foot, he returned through the barrens of western Kentucky to Louisville and from there to Frankfort and Lexington[863] (Figure 2). During his return to Philadelphia in the fall, he traveled by foot along the Zane Trace through the towns of Chillicothe, Lancaster, Zanesville, and Steubenville and thus

Figure 2. Ohio Valley localities recorded by Rafinesque in his *Life of Travels* (1836), from Pittsburgh to the mouth of the Wabash River and east to Lexington, May–September 1818. (1) Pittsburgh, Pennsylvania; (2) Steubenville, Ohio; (3) Wheeling, West Virginia; (4) Marietta, Ohio; (5) Letart Rapids = Letart Falls, Ohio; (6) Gallipolis, Ohio; (7) Neville, Ohio; (8) Cincinnati, Ohio; (9) Vevay, Indiana; (10) Louisville (including Shippingsport and the Falls of the Ohio), Kentucky; (11) Troy, Indiana; (12) Yellow Banks = Owensboro, Kentucky; (13) Evansville, Indiana; (14) Hendersonville = Henderson, Kentucky; (15) New Harmony on the Wabash, Indiana; (16) Shawneetown on the Ohio, Illinois; (17) Wabash River (mouth) (called Ohio River mouth), Illinois/Indiana; (18) Morgantown = Morganfield, Kentucky; [14] Hendersonville = Henderson, Kentucky; [12] Yellow Banks = Owensboro, Kentucky; (19) Green River (mouth), Kentucky; (20) Hardinsburg, Kentucky; (21) Salt River (mouth), Kentucky; (22) Sheperdsville, Kentucky; (23) Middletown, Kentucky; (24) Frankfort, Kentucky; (25) Lexington, Kentucky.

saw the southern portion of Ohio (Rafinesque 1818b) (Figure 3).

Rafinesque returned to Lexington in May 1819 (Figure 4) to assume his professorship at Transylvania University. During the next 6 years, as described in his *Life of Travels* (1836),[863] he botanized throughout Kentucky (Figures 4, 5, 6), preferring to walk rather than ride on horseback or take other means of travel. A map of the Ohio Valley (Figure 7) shows all of the locations mentioned by Rafinesque in his *Life of Travels*. These locations, already shown on the maps in other figures, give an approximation of where he botanized in the Ohio Valley, and particularly in Kentucky. Having been in various cities on the east coast in the summer of 1825, Rafinesque returned to Lexington in the fall of that year but left permanently the following spring. On this last trip from Lexington, taken on foot and by stage, he traveled on a northerly route through Ohio by way of Cincinnati, Dayton, Springfield, Columbus, Mount Vernon, Mansfield, and Milan to Sandusky on Lake Erie (Rafin-

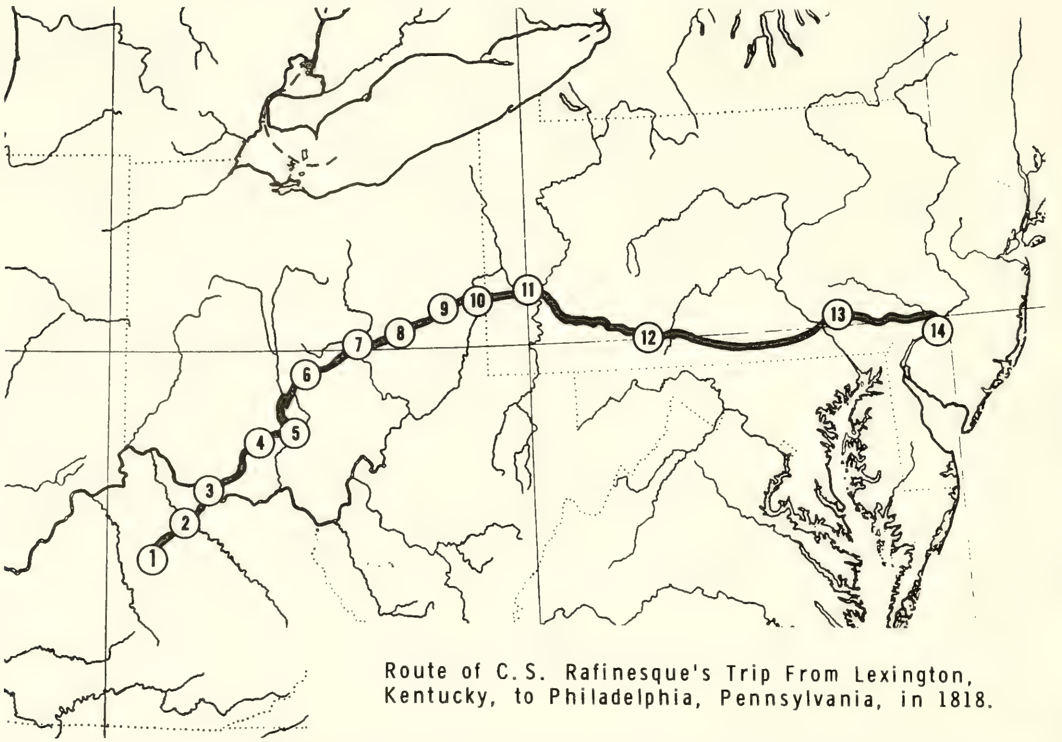


Figure 3. Rafinesque's route from Lexington, Kentucky, to Philadelphia, Pennsylvania, in 1818. (1) Lexington, Kentucky; (2) Blue Licks Spring, Kentucky; (3) Maysville, Kentucky, and Aberdeen, Ohio; (4) Bainbridge, Ohio; (5) Chillicothe, Ohio; (6) Lancaster, Ohio; (7) Zanesville, Ohio; (8) Cambridge, Ohio; (9) Cadiz, Ohio; (10) Steubenville, Ohio; (11) Pittsburgh, Pennsylvania; (12) Bedford, Pennsylvania; (13) Lancaster, Pennsylvania; (14) Philadelphia, Pennsylvania.

esque 1826). From there he went by steamboat to Buffalo, then across New York on the Erie Canal to Troy, down the Hudson River to New York City, and eventually to Philadelphia, his residence for the remainder of his life (Figure 8).

Rafinesque's enthusiasm for the study of plants in the field is perhaps best illustrated by a story told by the ornithologist John James Audubon (1785–1851). During Rafinesque's visit to Henderson, Kentucky, on the Ohio River, Audubon (1832) showed him a drawing of a plant common in the neighborhood. When Rafinesque declared that no such plant existed in nature, Audubon said that he could show it to him "on the morrow." But Rafinesque could not wait until then; instead, he asked to be taken immediately to the river bank, where he plucked plants one after another, and explained with great enthusiasm that he had not merely a new species, but a new genus. Together the two men went on field trips during the 3 weeks of Rafinesque's stay. The most memorable of the trips, described in great detail by Audubon, was one during which Rafinesque became lost while escaping into an enormous tangled canebrake (*Arundinaria*) following the sudden appearances of a black bear and a thunderstorm. Although Rafinesque collected multitudes of plants while in Henderson, he never again expressed a desire to visit a canebrake.

PUBLICATIONS DESCRIBING NEW OHIO VALLEY PLANTS

When Rafinesque entered the Ohio Valley in 1818, he had published within that year articles on several new genera and species of plants from the state of New York[275,279,281,284–286] in the first volume of the *American Journal of Science and Arts.* Established and edited by Benjamin Silliman (1779–1864) at Yale College, this periodical was to become the most prestigious scientific journal in North Ameri-

Figure 4. Ohio Valley localities recorded by Rafinesque in his *Life of Travels* (1836), from Pittsburgh to Lexington, May 1819; in Kentucky during the summer of 1819; and from Lexington to North Bend, Ohio, with Charles Wilkins Short, and return to Lexington, 1821. (1) Pittsburgh, Pennsylvania; (2) Marietta, Ohio; (3) Parkersburg, West Virginia; (4) Letart Rapids = Letart Falls, Ohio; (5) Maysville, Kentucky; (6) Washington, Kentucky; (7) Mayslick, Kentucky; (8) Blue Licks, Kentucky; (9) Paris, Kentucky; (10) Lexington, Kentucky; (11) Lancaster and Knob hills (large area), Kentucky; (12) Buttonlick and Harmon Lick, Kentucky; (13) Irvine, Kentucky; (14) Estil Springs and Wasioto Hills (large area), Kentucky; (15) Winchester, Kentucky; [10] Lexington, Kentucky; (16) Mount Sterling, Kentucky; (17) Olympia Springs, Kentucky; [10] Lexington and Elkhorn River, Kentucky; (18) Harrodsburg, Kentucky; (19) Chaumiere des Prairies and Nicholasville, Kentucky; (20) Mount Pleasant, a Shaker village = Shakertown, Kentucky; [10] Lexington, Kentucky; (21) Burlington, Kentucky; (22) North Bend, Ohio; (23) Miami River (mouth), Ohio; (24) Cincinnati, Ohio; (25) Big Bone Lick, Kentucky; [10] Lexington, Kentucky.

ca. Silliman published only seven of Rafinesque's papers on plants before he was warned by friends "at home and abroad" about Rafinesque's poor botanical judgments. He subsequently rejected and returned to Rafinesque a large bundle of submitted manuscripts. Twenty-some years later, Silliman (1841) wrote in a note:

> This [decision] will account for the early disappearance of his communications from this Journal. The step was painful, but necessary; for, if there had been no other difficulty, he alone would have filled the Journal, had he been permitted to proceed.

Good evidence now exists that the Ohio historian, antiquarian, and postmaster Caleb Atwater (1778–1867), of Circleville, was among those individuals "at home" who warned Silliman of Rafinesque, and that Atwater's malice was largely responsible for the beginnings of the permanent "fall from grace" of Rafinesque's reputation (Boewe 1987a). This idea is developed further in the section on Rafinesque's botanical associates.

Rafinesque's publications on botany during the time he was in the Ohio Valley appeared in foreign scientific journals, little-known lit-

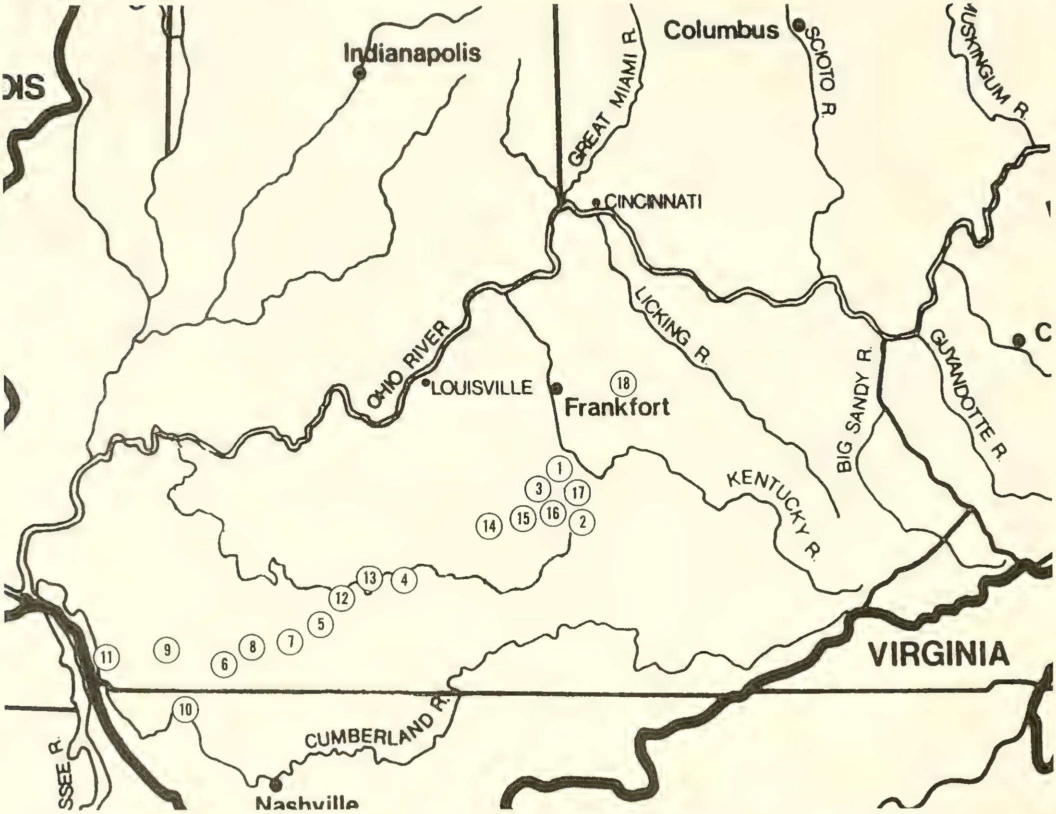


Figure 5. Kentucky localities (except Clarksville, Tennessee) recorded by Rafinesque in his *Life of Travels* (1836), for his route to the Tennessee River, May 1823. [18] Lexington; (1) Harrodsburg; (2) Cedar Lick, Lincoln County; Muldraugh's Hill (large area); Green River; (3) Rochester; (4) Elk Lick, Hart County; (5) Bowling Green; Cumberland River; (6) Elkton, Todd County; (7) "West Union, a village of Shakers" = South Union [?]; (8) Russellville; (9) Hopkinsville; (10) Clarksville, Tennessee; (11) Canton, Trigg County; [9] Hopkinsville; [8] Russellville; [7] "West Union"; [5] Bowling Green; (12) C[h]ameleon Spring, Warren County; (13) Mammoth Cave; Green River; (14) Cedar Lick, Marion County; (15) Knob Lick, Lincoln County; (16) Gov. Isaac Shelby's, Lincoln County; (17) Col. David Meade's, Jessamine County; (18) Lexington.

erary journals that were never firmly established, or in publications created by himself. His first communications on newly discovered genera and species were in letters to his friend Dr. Samuel L. Mitchill, who as editor published them in the *American Monthly Magazine and Critical Review,* issued in New York. Although Rafinesque began publishing in that journal in 1817, his first article[270] on new plants from the Ohio Valley appeared there in 1818. It was a letter, dated 20 July 1818 from Louisville, in which he outlined his discoveries in natural history made during his journey earlier that year. In the botanical portion of this letter, Rafinesque provided names and detailed descriptions for four new genera, each with a representative species. He also noted having 35 new species, but listed names for only 20 of them. On 5 October, in a letter[272] from Lexington, he wrote that he had 12 new genera and about 80 new species. One new genus, *Nevrosperma* (=*Momordica* L.) was fully described, as was a single species, *N. cuspidata* (=*M. balsamina* L.). He observed that it was an annual plant, cultivated under the name "balsam apple" in Kentucky, where he had collected specimens and seeds of the plant. He also named, adequately characterized, and provided information on habitats and localities for three other new species in other genera. In a paper[289] in the January 1819 issue of the *American Monthly Magazine,* Rafinesque noted that he had discovered two new genera and 25 new species of monocotyledons

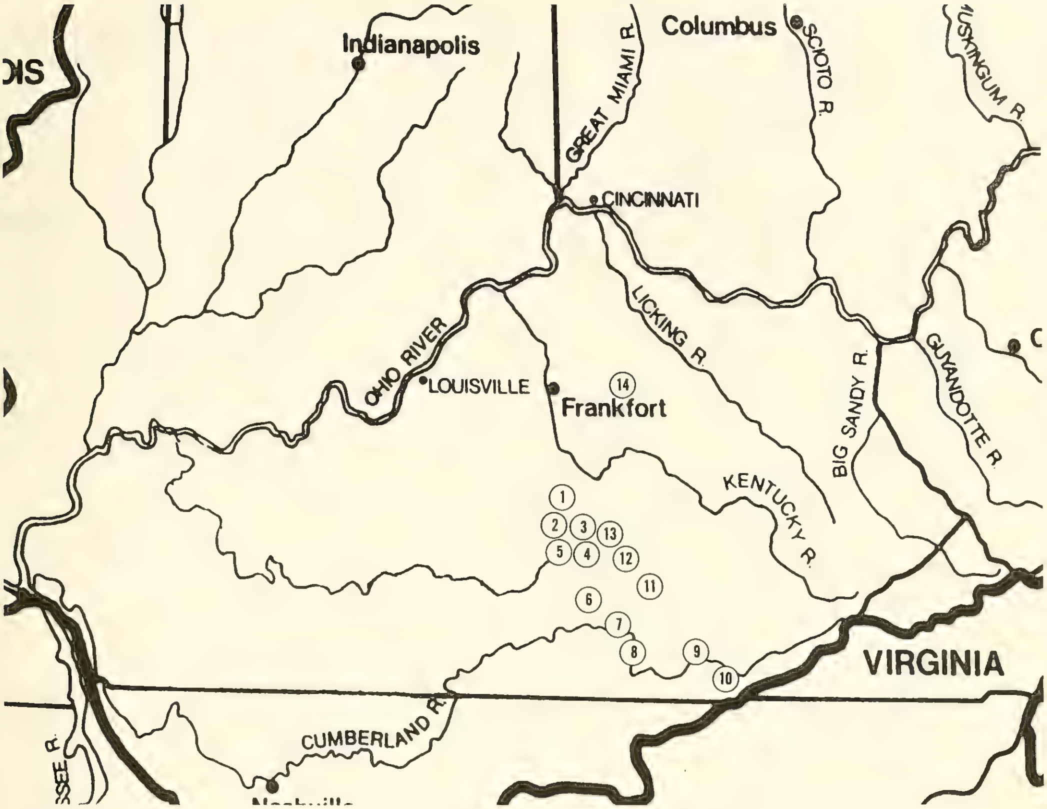


Figure 6. Kentucky localities recorded by Rafinesque in his *Life of Travels* (1836), for the Wasioto or Cumberland Mountains, in the south-central part of Kentucky, August–September,1823. [14] Lexington; (1) Danville; (2) Shelby [=property of Gov. Shelby, Lincoln Co.]; (3) Stanford; (4) Hall's Gap, Lincoln Co.; (5) Green River (source); (6) Somerset; (7) Rockcastle River (mouth); (8) Cumberland River (two falls); (9) Barbourville; (10) Pine Mountain, Bell Co. (also a mountain range); Poplar Mountains; (11) Hazelpatch, Laurel Co.; (12) Mount Vernon; (13) Crab Orchard; [3] Stanford; (14) Lexington.

and 12 new genera and 125 new species of dicotyledons. These numbers of new genera and species are evidence of the rapid pace at which Rafinesque must have worked during his first field season in the Ohio Valley.

Rafinesque continued to publish newly discovered taxa from the Ohio Valley and other parts of the country in the *American Monthly Magazine* from 1817 through 1819[249,251–253,291–295] and the *American Journal of Science* in 1818 and 1819.[275,279,281,284–286] Perhaps the most noteworthy species from the western states described in the latter journal was his *Myosurus shortii* (=*M. minimus* L.),[286] received from, and named in honor of, Charles W. Short of Hopkinsville in the barrens of western Kentucky, where Short had obtained the plant. In four of the published papers[270,272,286,289] cited above, four new genera and eight new species of vascular plants were actually described from the Ohio Valley. Based on Merrill's (1949) data, the only one of these taxa not placed in synonomy is *Dodecatheon angustifolia,* the identity of which remains unknown. Merrill's analysis shows that these taxa were not really new to science and that the journal editors were probably justified in returning Rafinesque's manuscripts.

Damaging though this rejection may have been to Rafinesque's self-image, it was for the better of science. Rafinesque, however, did not curtail his research but instead turned to other outlets to publish his descriptions of new plants. He found receptive periodicals in Paris in the *Journal de Physique, de Chemie, d'Histoire Naturelle et des Arts* in 1819 and

Figure 7. Map of the Ohio Valley showing all of the locations mentioned by Rafinesque in his *Life of Travels* (1836), including all of the locations shown on the maps in other figures, giving an approximation of where he botanized in the Ohio Valley, and particularly in Kentucky.

1820,[300,368] and in Brussels in the *Annales Générales des Sciences Physiques* in 1820 and 1821.[340,341,345,346,350,351,353,356,374] He described 50 new genera in his first article[300] in the *Journal,* which Asa Gray (1841) noted was "probably one of Rafinesque's most creditable productions." Later articles[351,368] described the new genus *Enemion* and its type species, *E. biternatum.* In the *Annales Générales,* he published revisionary or monographic treatments of *Rosa*[340] and *Houstonia*[341] and remarks on the genera *Viscum,*[345] *Samolus,*[345] *Viburnum,*[345] *Jeffersonia,*[350] *Enemion,*[351,359] *Trillium,*[353] *Tridynia,*[356] *Steironema,*[356] and *Lysimachia*[356] and the family Convolvulaceae.[374] Some of these papers were reprinted at later dates.

At home in Kentucky, Rafinesque turned to newly formed literary journals in Lexington as outlets for publication of his new taxa. In 1819, in an article[307] in the *Western Review and Miscellaneous Magazine,* edited by Harvard College graduate William Gibbes Hunt (1791–1833), Rafinesque described two species of new shrubs, *Betula rupestris,* the rock birch, and *Cornus obliqua,* the obliqual dogwood of Kentucky. They were discovered growing together on the rocky sandstone cliffs of the Kentucky River in Estill County. Rafinesque thoroughly characterized each species by writing in English a specific definition, or diagnosis, a full description, a number of observations on habitat, locality, and phenology, and comparisons with closely related species made from personal observations of living plants and from the literature. His name for

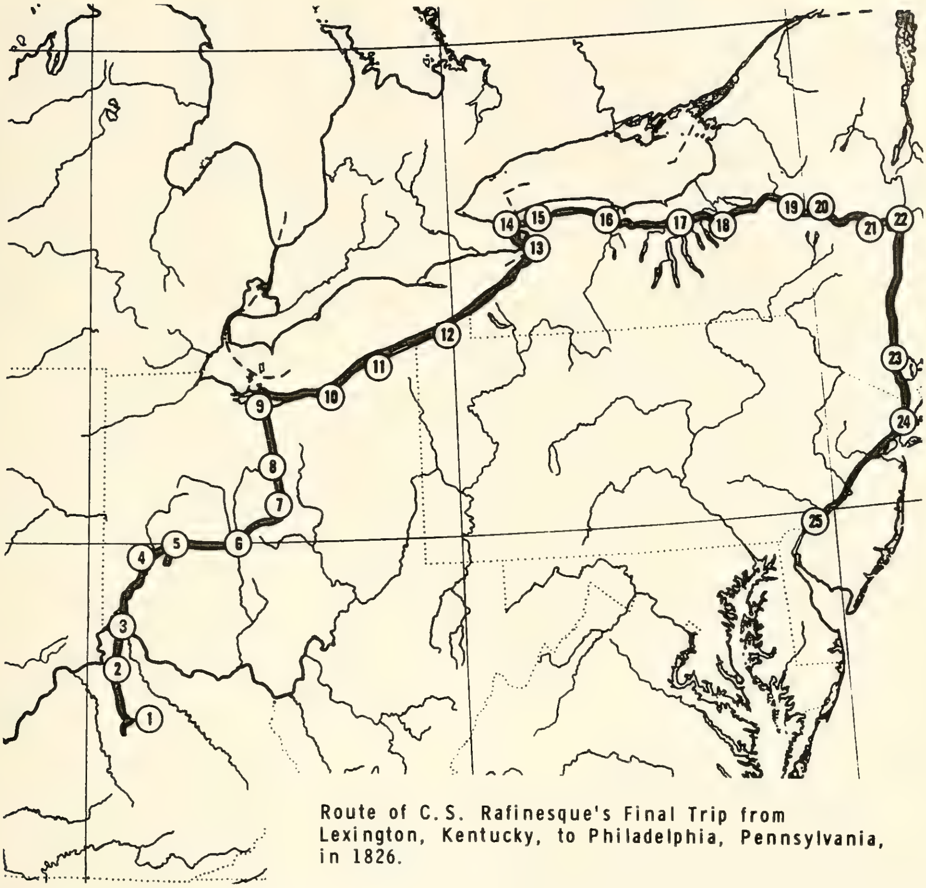


Figure 8. Rafinesque's final route from Lexington, Kentucky, to Philadelphia, Pennsylvania, in 1826. (1) Lexington, Kentucky; (2) Williamstown, Kentucky; (3) Cincinnati, Ohio; (4) Dayton, Ohio; (5) Springfield and Yellow Springs, Ohio; (6) Columbus, Ohio; (7) Mt. Vernon, Ohio; (8) Mansfield, Ohio; (9) Portland (now Sandusky), Ohio; (10) Cleveland, Ohio; (11) Fairport, Ohio; (12) Erie and Presque Isle, Pennsylvania; (13) Buffalo, New York; (14) Niagara Falls, New York; (15) Lockport, New York; (16) Rochester, New York; (17) Montezuma, New York; (18) Syracuse, New York; (19) Utica, New York; (20) Little Falls, New York; (21) Schenectady, New York; (22) Troy, New York; (23) West Point, New York; (24) New York, New York; (25) Philadelphia, Pennsylvania.

the dogwood is accepted, and the name for the birch remains to be evaluated. The description of the latter plant would match *B. pumila* were it not for the fact that Kentucky is far to the south of that species' natural range (John J. Furlow, pers. comm.).

Believing that the general public had as much interest and enthusiasm for the details of natural history as he himself had, Rafinesque wrote popular articles on various topics for a local newspaper, the *Kentucky Gazette,* between 1820 and 1822, under the general heading "The Cosmonist." Of those articles known to survive, three concern botany.[441,442,447] One article[442] contained descriptions of, and observations on, two spring flowering herbs, *Enemion biternatum* and *Stylypus vernus,* that he discovered near Lexington. Rafinesque had previously named and described the two species as new to science in European journals, and he apparently was quite fond of them, for he wrote enthusiastically of their discovery in a letter of 1 December 1820 to Professor Augustin Pyramus DeCandolle, to whom Rafinesque referred as the first botanist of the European continent. The description of these new plants in the *Kentucky Gazette* made it possible for them to

be known to the local readership. Both of the plants are now considered distinct species, but Torrey and Gray placed them in different genera, where they have remained under the names *Isopyrum biternatum* (Raf.) Torr. & Gray and *Geum vernum* (Raf.) Torr. & Gray, respectively. In the *Flora of North America*, Rafinesque's genus *Enemion* is recognized as a genus with five species, including *E. biternatum* Raf. (Ford 1997).

A second paper[447] listed 16 species and common names of the roses of the United States, all of which Rafinesque had described in 1820 in the *Annales Générales*. In addition, this paper includes a description of one new species, *Rosa viscida* (=*R. virginiana* Mill.). Rafinesque urged the cultivation of these new roses in the gardens of Lexington. These two articles and the third one[441] on the botany of the western limestone region, discussed below, were all quite technical, differing little in terminology from his articles in the scientific and literary journals. Of these articles under the heading "The Cosmonist," Rafinesque (1836, p. 65)[863] later admitted that he "could not make Nat[ural] history popular."

Rafinesque also sent papers on new taxa to the *Cincinnati Literary Gazette*, published by John P. Foote (1783–1865). Through this outlet he initiated a series of papers called "Neophyton," of which four numbers are known to have been published. In them he named and described the new genus *Cladrastis* and its type species, *C. fragrans*,[452] two new species and eight new varieties of *Collinsia*,[453] the species *Prenanthes opicrina*,[463] and the new genus *Lophactis* with its type species, *L. uniflora*.[464] These papers contain a number of similarities. In addition to the formal presentation of the binomial names and short formal diagnoses in English, Rafinesque gave detailed remarks on many aspects of the plants, including when and where he first discovered them, how the plants differed from related taxa, blooming time, origin and meaning of common names, practical uses, detailed notations on habitat, and names used by other botanists who already had seen the plants. These papers give much accurate information about the plants, and they represent examples of very complete taxonomic studies for the early 19th century.

The paper on *Collinsia*[453] is a revision of this North American genus, in which Rafinesque unnecessarily, but for his own reasons, renamed Nuttall's *C. verna*, the type, as *C. bicolor*, with six new varieties, and described two new species, *C. alba* and *C. purpurea*, the latter with two varieties. In assigning the names to these three species, Rafinesque reasoned that since they were all vernal species, *C. verna* had been improperly named by Nuttall. Accordingly, Rafinesque named the three species by the color of their flowers. The first, *C. verna*, with bicolored white and blue corollas, became *C. bicolor*; the white-flowered one, *C. alba*; and the purple-flowered one, *C. purpurea*. Of his proposed new taxa in the four papers in the *Cincinnati Literary Gazette*, only the monotypic *Cladrastis* is maintained today, as *C. lutea* (Michx. f.) K. Koch according to many authors. Rudd (1971) adopted the name *C. kentukea* [as "*kentuckea*"] (Dum.-Cours.) Rudd, based on a description of 1811 by Dumont de Courset, who had young, non-flowering specimens cultivated in France. The genus *Cladrastis* was accepted early by John Torrey, who wrote Rafinesque that it "is a very good one."[661] Rafinesque recommended cultivation of *Prenanthes opicrina* (=*P. crepidinea* Michx.) as a source of medicinal compounds. Merrill (1949) questioned whether the *Lophactis*, which Rafinesque redescribed in 1832,[732] might be a *Coreopsis*, but Tod F. Stuessy (pers. comm.) believes it is a *Silphium*.

The format, style, and generally informative details of these writings are those of quality presentations; in this respect, these papers contain valuable and useful information on natural history of the plants. However, the taxonomic decisions that Rafinesque made as the initial justification for these papers now make them mostly worthless as taxonomic studies. All of the species of *Collinsia* in eastern North America are considered to be one, *C. verna* Nutt. Rafinesque's paper on *Collinsia* is an example of the extremes to which he would go to describe all of the variants in a genus with a single species.

To further the cause of making known his discoveries of new western plants, Rafinesque published in Lexington his *Annals of Nature*[370] in 1820, and his own journal, the *Western Minerva*[375,390] in 1821. In the latter journal Rafinesque published an article[391] on botanical discoveries made in Kentucky, extracted from a letter of 1 December 1820 to Augustin Pyr-

amus DeCandolle of Geneva, Switzerland. Another article[392] is a taxonomic revision of the genus *Clintonia,* taken from a letter of 26 September 1819 to Dr. Samuel L. Mitchill of New York. In a later article,[432] Rafinesque alleged that his "secret foes" paid his printer to suppress the *Western Minerva,* but he saved three copies of the first and only number, from which Fox (1900) published a detailed synopsis of its contents. Rafinesque's last taxonomic botanical publication while he was a resident of Lexington was a four-page pamphlet, *Neogenyton* (1825),[474] dedicated to Professor DeCandolle, that described 66 new genera of North American plants. However, new taxa of western plants continued to appear in his writings after he returned to Philadelphia in 1826. Several of these items appeared as short articles in his *Atlantic Journal and Friend of Knowledge* (1832–1833)[623,727–729,731,732,749,785] and in his *Herbarium Rafinesquianum* (1833).[757,779,786,795,797,798,800,802–805,817–819] He described individual taxa in his books, among them the two-volume *Medical Flora* (1828–1830),[554,557] *American Manual of the Grape Vine* (1830),[558] *New Flora and Botany of North America* (1836–[1838]),[868] *Flora Telluriana* (1836 [1837–1838]),[873] *Alsographia Americana* (1838),[883] *Sylva Telluriana* (1838),[885] *American Manual of the Mulberry Trees* (1839),[894] and *Autikon Botanikon* (1840).[897]

Much of Rafinesque's taxonomic work in botany remained obscure until Merrill published his comprehensive *Index Rafinesquianus* (Merrill 1949). Several years in the making, this invaluable index lists all of the known names proposed by Rafinesque, their sources of publication, and their modern equivalents when known. This single most important and indispensable compendium unlocks the information that Rafinesque so widely, yet obscurely, published in North America and Europe.

In a study limited to the plants of Indiana, Friesner (1953), also using Merrill's *Index*, determined that Rafinesque had named 22 plants from Indiana, and that, of these, only one name, *Oenothera pilosella,* was still recognized in the flora of that state. The nomenclature Friesner used was according to the eighth edition of *Gray's Manual* (Fernald 1950). All 22 names, along with their sources of publication and modern equivalents, if known, were listed in Friesner's paper. Friesner further reported that Rafinesque proposed 1210 names for the plants known in the 1950s to grow in Indiana, but only 33 (or 2.73%) were still in use at that time.

To gain a similar idea of the number of species that Rafinesque named and described from the Ohio Valley, I tallied the plant names that Merrill noted with the abbreviations "*descr.*" or "*nom. nota*" for the Ohio Valley states. The totals were 70 from Illinois, 19 from Indiana, 320 from Kentucky, 166 from Ohio, and 37 from Tennessee, for a total of 612 new taxa. The 166 taxa named from Ohio included 118 from along the Ohio River and along Lake Erie. When these 118 names are excluded, 48 names remain. Forty of these 48 are species in which four epithets are retained, with two in their original genera and two transferred to other genera. Twenty-four of the specific names have been placed into synonymy, and twelve remain unknown. The remaining eight names are varieties, and their identities also remain unknown. Rafinesque's two accepted species described from the Ohio flora are *Acalypha rhomboidea* and *Tradescantia ohiensis,* and the two whose epithets have been transferred to other genera are *Camassia scilloides* (Raf.) Cory and *Isopyrum biternatum* (Raf.) Torr. & Gray, although the latter has been returned to *Enemion* (Ford 1977).

In a broader perspective for eastern North America, Call (1895) wrote that 13 genera, 8 subgenera, and 16 species established by Rafinesque appeared in the sixth edition of the *Manual of the Botany of the North United States* by Gray, Watson, and Coulter (1890). He predicted that others would be added with the advance of time and that "the full sum of tardy justice eventually will be reached." Examination of the eighth, most recent, and most geographically comprehensive edition of *Gray's Manual* (Fernald 1950) indicates a current recognition of 18 genera, 84 species, and 13 varieties, as determined by me.

BOTANICAL ASSOCIATES AND CORRESPONDENTS IN THE OHIO VALLEY

As was his practice everywhere he traveled, Rafinesque sought to meet and socialize with botanists of the Ohio Valley and to obtain information about plants from them. Furthermore, he was always quick to express his

thanks to others. As a result of this practice, he left several more or less detailed inventories[251,554,749,788,863,868] of contemporary American botanists; from these lists, the range and nature of his personal associations may be largely reconstructed. Boewe has provided identifying annotations for many of the more obscure persons that Rafinesque named in his autobiography (Rafinesque 1987).

The acknowledgements in Rafinesque's *Medical Flora* (1828)[554] are especially noteworthy in that some of the names there do not appear in any of Rafinesque's other lists. Of the 16 persons named, seven were from the Ohio Valley. Otherwise, the proportion of westerners in the remaining lists is invariably lower. For example, in Rafinesque's "Account of the botanical collections . . . ,"[749,788] published in 1832, he named 57 persons who had contributed to his herbarium. Forty-four were Americans, and only 11 of these are known to have resided in the Ohio Valley at any time. In his last known list, the "Historical sketch" at the beginning of the second part of his *New Flora* . . . (1837),[868] Rafinesque named 25 American collectors who had contributed to his herbarium. Only nine of these are known to have resided in the Ohio Valley at any time. These statistics indicate that, although Rafinesque was the most prolific collector of plants in the Ohio Valley, he still relied heavily on botanists of Europe and the eastern seaboard to supply him with specimens.

Ohio Valley residents acknowledged as sources of information on medicinal plants by Rafinesque in his *Medical Flora* (1828)[554] were Drs. Short and Brown of Lexington, Dr. Eoff of Wheeling, Dr. Müller of New Harmony, Dr. Drake of Cincinnati, Dr. Crockett of Frankfort, and Dr. Graham of Harrodsburg. The Ohio Valley residents who contributed to his herbarium were identified by Rafinesque in subsequent publications[749,788,868] as follows: Bradbury, Dr. "Crockatt" [in 1832] or "Crocket" [in 1837], "Mrs. Mary Holley born Austin," Dr. Locke, Dr. "Miller" [Müller], Dr. Short, Miss Jane Short, John C. Short, Ridgely, Steinhauer, and Dr. Ward. Of the western contributors to Rafinesque's herbarium, all except John Locke, Frederick Ridgely, and Daniel Steinhauer are discussed below. Dr. Crockett, like Rafinesque's other students, is discussed below in the sub-section on "Botanical Instruction."

* * *

As early as 1810, the English plant collector John Bradbury (1768–1823) had explored the Missouri Country, at the particular encouragement of Thomas Jefferson (True 1929; Rickett 1950). Bradbury's subsequent book, *Travels in the Interior of America,* was published in London in 1817, and few readers could have been more susceptible to that book's sense of adventure than Rafinesque. This book could only have served to reinforce any pre-existing thoughts that Rafinesque may have had of relocating to the trans-Allegheny region.

In his *Life of Travels* (1836, pp. 57, 64),[863] Rafinesque recalled visiting "my friend Bradbury" as he passed through Middletown during his first foray into Kentucky in 1818, and then recalled that "In 1822 Bradbury came to see me: he had sold me in 1817 many new plants of Missouri, and I had written a *florula missurica,* which I sent to Swainson [the zoologist and traveler William Swainson (1789–1855)] in England, whom I fear never received it." Thus, his most significant interaction with Bradbury had already taken place by the time Rafinesque came to the Ohio Valley in 1818.

Rafinesque sought to commemorate Bradbury in the new genus *Bradburya,* published in the *Florula Ludoviciana* in 1817, but the genus *Wisteria,* named by Nuttall in 1818, was later conserved over Rafinesque's name. Rafinesque continued to acknowledge Bradbury, who was among eight named "*Botanical Authors* . . . who have added to my N.Amer. herbals" (Rafinesque 1832).[749,788] Five years after making this acknowledgement, Rafinesque (1837)[868] named Bradbury repeatedly in his exhaustive lists of writers, "friends and assistants" from whom ". . . I have received much help by gifts or exchanges of specimens, new facts and observations," and "Botanical travelers who . . . come to explore our Plants in order to send them to European Gardens or Herbals . . . ."

* * *

The traveling English naturalist Thomas Nuttall (1786–1859), then based in Philadel-

phia, suggested to Rafinesque that he should make the acquaintance of the young Kentucky physician Charles Wilkins Short (1794–1863), who was just beginning his illustrious botanical career (Perkins 1938; Davies 1945). Nuttall had been impressed with Short's knowledge of plants when they botanized together in the vicinity of Lexington during the summer of 1816. Arriving in Cincinnati in the summer of 1818, Rafinesque met Dr. Short's older brother, the lawyer John Cleves Short (1792–1864), and the two men spent a day at John Short's residence at North Bend, on the Ohio River about 15 miles below Cincinnati. Botanist Short was not present at this meeting. The previous year he had moved from Lexington to Hopkinsville, a small Christian County town, in the barrens of western Kentucky, where he expanded his medical practice and speculated in land.

Upon his arrival in Louisville, Rafinesque wrote his first letter to Dr. Short on 17 July 1818. Concerning plants, he stated:

> I regret exceedingly that I cannot visit your part of the country and see your herbarium, as it is my wish to become acquainted with the geographical range of all the plants of the western country. I have seen a few of your plants at your brother's and have determined most of them, having with me Pursh's Flora & Persoon's sinopsis. I am able to determine any plant that I see. I will mention the *Orchis spectabilis* of L[innaeus]. as an instance, which you sent to your brother as an unknown plant.

Rafinesque proposed to Short that he send his herbarium, or any part of it, to Lexington, where later in the summer Rafinesque would be able to provide the names for all of Short's plants, and to exchange duplicate specimens. On 15 September 1818, Short reportedly returned a letter and a parcel of 44 specimens, to which Rafinesque gave names, and of which 12 were new to science (Perkins 1938). Rafinesque's notes on the plants were enclosed in a letter of 27 September 1818. With this exchange began a correspondence that spanned the next 19 years. Twelve letters from Rafinesque to Short (Perkins 1938; Davies 1949; Boewe 1980) and one from Short to Rafinesque (Boewe 1961) are known to have survived. Short's handwritten "Memoranda of Letters" (1816–1824) contains notations of at least four other letters written to Rafinesque between 1818 and 1822.

Rafinesque's letters covered many topics—for example, exchanges of plants and publications, identifications of and notes about plants, comments on his travels, and his work at Transylvania University. In addition to having Short collect and send him plants, especially the vernal ones of western Kentucky, Rafinesque, in a letter of 27 September 1818, outlined many other projects, which "may increase your meritorious labours." As Short was a good artist, Rafinesque wanted a drawing "of any other rare, peculiar, new or doubtful plant" of Kentucky. Later, on 15 June 1820, Rafinesque again urged Short to illustrate plants, for "We may afterwards do something with them for the advantage of science." Still later, on 16 November 1827, when Rafinesque was writing his *Medical Flora* (1828–1830),[554,557] he requested from Short illustrations of rare medicinal plants and general information on *materia medica,* a subject Short had been teaching at Transylvania University since 1825. Rafinesque asked Short to obtain data from distant students who knew of medicinal uses of plants, and he wanted Short's former students from Alabama to send him plants from that state. Rafinesque must have been grateful for Short's contributions of specimens and illustrations, for he dedicated his *Medical Flora* to John Torrey, Short, and Stephen Elliott, three American botanists he held in high esteem. During the course of his writings, Rafinesque commemorated Short's name in one genus, *Shortia* (*S. dentata*), and in two specific epithets, *Myosurus shortii* (=*M. minimus* L.) and *Gentiana shortiana* (=*G. saponaria* L.).

Rafinesque and Short met on two occasions: in Lexington in September 1821, and in Hopkinsville in the early summer of 1823. The meetings were described briefly in Rafinesque's *Life of Travels* (1836, pp. 64, 69).[863] Traveling in Short's carriage on the Ridge Road, the two men botanized along the 82-mile route from Lexington to Cincinnati and on to North Bend, where they explored at the mouth of the Big Miami River and visited Short's brother and his uncle William Henry Harrison (1773–1841), a general and later the ninth United States president.

Rafinesque's activities in this neighborhood were not forgotten. More than 50 years later, on 27 December 1879, Dr. John A. Warder,

who had purchased a part of the Harrison estate, wrote to George Engelmann of St. Louis regarding the recognition of *Catalpa speciosa* as a distinct species:

> and right here (North Bend) where Gov. Harrison had introduced it, the plant seems to have escaped the notice of all the botanists, Clark, Thos. Lea, R. Buchanan, Drs. Locke & Riddell, Dr Wm Short [sic] of Kentucky who often visited his brother near us, who had planted many trees obtained from Genl. Harrison, and even Rafinesque himself who botanized in this region–

From North Bend, Rafinesque went on horseback to explore Big Bone Lick, about 18 miles south of Cincinnati, noting in a later article[609] that he "collected several plants," and that "Many pretty plants are found in the valley and hills, but no saline plants." After Rafinesque had explored the area for several days, Short met him there, and together they returned to Lexington. This first visit must have been cordial, as Rafinesque wrote to Short on 1 February 1822 that Short's "renewed invitation to visit your part of the Country, Barrens &c meets my long delayed wishes." These wishes later came true during Rafinesque's travels into western Kentucky in 1823, when he and Short together studied plants of the barrens.

No letters passed between Rafinesque and Short after their parting in Hopkinsville in 1823, until Short reportedly sought to renew the exchange of dried plant specimens and information on medicinal plants in letters of 16 November 1827 and 5 August 1834 (Perkins 1938). Meanwhile, Rafinesque had moved to Philadelphia and Short to Lexington. On 7 September 1834, Short replied that, for the past 3 or 4 years, he had "been very industriously engaged in collecting and preserving the plants of Kentucky . . ." and that he had sent about 5000 specimens of about 600 species to various correspondents in Europe and America. He was already honor bound to send plants to these botanists during the forthcoming winter, but because his supply of specimens was sufficient, he would have plants enough for Rafinesque. Short imposed one condition: he wanted at least one parcel of plants containing Rafinesque's novelties from Kentucky before he would exchange any more plants with him. Rafinesque had apparently promised to send specimens to Short and none had been received.

On 25 October 1834, in response to Short's condition, Rafinesque promised a small package, but in reality he needed money and wanted the affluent Dr. Short to buy his plants. He wrote:

> You will see in the last [letter] that I offer my whole Herb[arium]. for sale, the whole or in parts at specific prices; and it is for this that I reserve my numerous & rarest Discoveries. I shall not be able to send you for Exchange all my N[ew]. Sp[ecies]. & G[enera]. because I have already disposed of most Duplicates & expect N[ew]. Sp[ecies]. or very rare ones in return. But you may expect some if you send me New things, or you may buy my standard Monographs. However my N[ew]. Sp[ecies]. from Kentucky may be found again by you, & I will willingly acquaint you with their location that you may look for them, & comply thus with your request. Nay I look upon you to supply me again with some very rare plants which I have sent to Europe & have only single specimens left. But this will be only for next year['s] herborizations. This year you can only supply me the Gentians or such as you have collected & have to spare. By the numerous list of your correspondents to whom you are to send plants, I am afraid you will have few left for me, & hardly time to attend to my Demands. Yet I recommend you to send any Doubtful plant from Kentucky, as I know them so well that I can more easily give you their names than anybody else.

This passage certainly reveals the self-centeredness in Rafinesque's approach to botany. He did comply with Short's condition by sending a small package which, as recorded in his letter of 15 November 1834, consisted of sets of 54 American plants and twelve "Oriental plants . . . from Egypt, Palestine & Greece . . . sent as a Sample." The American plants were chiefly from the seashore, the barrens, the Allegheny Mountains, and the Carolinas, but none was from Kentucky.

My search in July and August 1965 at the Herbarium of the Academy of Natural Sciences of Philadelphia, where Short's herbarium is deposited, revealed 49 specimens of eastern North American plants that Short had obtained from Rafinesque (Stuckey 1971a). With the exception of three specimens, all of them contain locality data, including 20 from the Allegheny Mountains of Pennsylvania, but none of the specimens had the name of a Kentucky locality or even the name "Kentucky" itself. These specimens bear the original blu-

ish gray labels with the names of the plants and their localities in Rafinesque's handwriting, along with the printed stamp, "C. S. Rafinesque Philadelphia, Pa.," usually in the bottom left-hand corner. Rafinesque also stated in his letter of 15 November 1834 that he had put aside 100 other plants for Short, but apparently they were not sent. Nor, apparently, did Short ever receive any of Rafinesque's specimens from Kentucky.

Of the few specimens that he received from Rafinesque, Short had nothing positive to relate. Writing to John Torrey on 11 August 1835, Short stated that Rafinesque's package "contained a miserable parcel of things, most of them as familiar to me as a 'thrice told tale', together with some faded fragments of exotic affairs, rendered imposing and venerable by being labelled from 'Etna', 'Egypt', and 'Palestine' &.c&.c" On 10 May 1841, in a letter to William Darlington of West Chester, Pennsylvania, Short described Rafinesque's plants as "so miserably bad that they have been eyesores to me whenever I have met them . . . ." As also noted in his letter of 11 August 1835 to John Torrey, Short had sent a considerable collection of plants to Rafinesque that spring, but it is not known if these were received.

On 7 November 1837, in his last known letter to Short, Rafinesque expressed annoyance toward Short for not having sent specimens of rare plants from Illinois and western Kentucky, as supposedly promised. He made additional demands of Short by insisting that Short purchase his published works and the rare plants he had recently acquired from the herbarium of Zaccheus Collins. Rafinesque wanted specimens of all the gentians and other rare plants of Kentucky and Illinois, including specimens of those taxa that he had already described. He begged for Short's publications and new botanical information on Kentucky. As a favor, Rafinesque also asked for the names of all the botanists and botanical collectors known to Short in the west and south, because he wished "to make a complete list of Authors, Works, pamphlets, collections, herbals, gardens, Collectors, travellers &c in N. America."

Because only one of Short's letters to Rafinesque is known to survive, Short remains the silent partner in their botanical interactions prior to 1834. It appears that Rafinesque extracted from Short as much botanical information as possible and that Short, with his characteristic reserve and quiet manner, calculated the situation carefully and was completely generous and cooperative. Even in Short's one surviving, and apparently last, letter of 7 September 1834, he displays a sense of annoyance because Rafinesque had not fulfilled his earlier promises to send specimens and provide localities of his new plants from Kentucky. Short evidently was not about to purchase Rafinesque's books and plants just to confirm information on a flora he already knew quite well. After 1835, as is well documented from Short's letters to John Torrey, William Darlington, and Asa Gray, the meticulous Dr. Short became totally disenchanted with the erratic Rafinesque and his slipshod and self-aggrandizing botanical work (Stuckey 1986). Apparently Short responded to no more of Rafinesque's demands after 1835.

* * *

In 1818, at New Harmony, on the banks of the Wabash River in southern Indiana, Rafinesque met Dr. Johann Christopher Müller (1777–1845), the doctor, schoolmaster, and official musician of the Harmony Society. Müller had accompanied the Rev. George Rapp, the Society's founder, to Economy, Pennsylvania, in 1803. From 1814 to 1824, the Society functioned at New Harmony. In 1825, Rapp sold the community to Robert Owen and returned to Economy with Müller, who there served as Curator of the Museum of Natural Curiosities (Pitzer and Elliott 1979). As noted in Rafinesque's *Life of Travels* (1836, p. 56),[863] Müller "had a fine herbal [herbarium] and gave me some fine plants: we went together to herborize in the meadows." Over the course of his career, Rafinesque published species of plants that he and Müller collected together from the Wabash country in 1818, or that Müller later gave to Rafinesque. These plants were: *Amorpha tomentosa* (=*A. canescens* Pursh),[897] *Collinsia purpurea* (=*C. verna* Nutt.),[729] *Cuscuta aphylla* (=? *C. glomerata* Choisy),[272] *Dodecatheon angustifolium*,[272] *Helichroa fuscata*, *H. crocea*, (both =*Echinacea purpurea* (L.) Moench),[729] *Lophactis uniflora* (=*Silphium* sp.)[464,732] and *Tradescantia rupestris* (= *T. virginiana* L.).[729] In his paper on *Collinsia*,[453] Raf-

inesque wrote that Müller was the first to discover a species in this genus, the plants having come from Economy near Pittsburgh. Müller had sent the plants to the Rev. Henry Muhlenberg of Lancaster, who mistook them for a new species of *Herpestis*. Müller was the first to discover Rafinesque's new *C. purpurea* (=*C. verna* Nutt.) on the Wabash in Indiana. It is not known if Müller's own herbarium has survived, but a few of his specimens were given to Dr. William Darlington in 1816 and to the Rev. Lewis David von Schweinitz in 1831, when these two botanists visited Economy during westward journeys. A few of Müller's specimens are now in the Darlington Herbarium (DWC) at West Chester State College, Pennsylvania, and in the Schweinitz Herbarium at the Academy of Natural Sciences of Philadelphia (PH).

* * *

Rafinesque corresponded with Ohio historian and antiquarian Caleb Atwater (1778–1867), who was the postmaster at Circleville. Atwater's publications include several pioneering papers on the prairies of Ohio (Atwater 1818, 1827, 1831, 1838). In his *Life of Travels* (1836, p. 62),[563] Rafinesque commented that he had "sent a florule of Ohio" to Atwater, probably no later than 1819, but nothing was ever learned by its author concerning the fate of this work. It may have been titled "Flora of the State of Ohio or Catalogue of its plants," which appeared as item number 66 in the catalogue of 100 works, essays, and manuscripts that Rafinesque appended to his 15 February 1824 letter to Thomas Jefferson, as part of an application for a faculty appointment in the newly created University of Virginia (Betts 1944). Although Atwater included lists of plants in his *History of the State of Ohio* (Atwater 1838), the information is credited to other individuals who evidently were the authors.

As mentioned earlier, Boewe (1987a) has presented evidence that Atwater was among those individuals who warned Benjamin Silliman of Rafinesque's scientific indiscretions. The first evidence of animosity between Atwater and Rafinesque appeared in Atwater's *Archaeologia Americana* (Atwater 1820a). Although it was based on careful field examination, this survey of prehistoric Indian mounds included acknowledgements to many contributors. Among them was Rafinesque's friend and patron John D. Clifford, but no mention of Rafinesque was made, even though he and Atwater had been in correspondence on the subject of antiquities for some time. Rafinesque (1820)[958] reviewed Atwater's survey in the *Western Review and Miscellaneous Magazine,* published in Lexington in September 1820, and when Atwater saw the review, he became furious with Rafinesque, and in a letter of 20 October 1820 to Isaiah Thomas (1749–1831), the president of the American Antiquarian Society, Atwater stated that Rafinesque had inserted into the review "more than one hundred base falsehoods as were ever uttered by man."

Atwater's malice, as expressed to Silliman, was undoubtedly a primary factor in the destruction of Rafinesque's reputation. In his *Life of Travels* (1836, p. 62),[563] Rafinesque seemed to gloss over the whole matter by noting simply that Atwater "quarrelled with me when he found that I was likely to take up the subject [of antiquities]." In a letter[413] of 7 January 1821 to Bory St. Vincent (1778–1846), editor of the *Annales Générales des Sciences Physiques* of Brussels, Rafinesque described Atwater as "an able man; but a diffuse writer, his style being deprived of order, perspicuity and elegance."

* * *

The Indiana botanist identified only as "Dr. Ward" has received inordinate attention from researchers due to his involvement with the *Walam Olum,* an alleged Delaware Indian tribal chronicle the pictographic part of which he is supposed to have obtained and given to Rafinesque sometime between 1820 and 1822. No fewer than four possible "Drs. Ward" have been named in the literature, but in no instance is there an exact or compelling correspondence between Rafinesque's own sketchy description of his source and the biographical data otherwise available (Weer 1942, 1954; Barlow and Powell 1986; Boewe 1987b). The candidates are Dr. John Russell Ward, Dr. William Ward, and the Rev. John Ward, all of Kentucky, and Dr. Malthus A.W. Ward, who did indeed reside briefly in Indiana.

Rafinesque apparently made his first reference to "Ward" in a letter of 24 September 1822, to Zaccheus Collins, in which he announced his intention to name in Ward's honor a St. John's-wort, *Hypericum wardianum* (Barlow and Powell 1986; Boewe 1987b). Boewe pointed out that "*Hypericum wardianum* is a manuscript name that never saw publication . . . ," and regarded this eponymy as evidence for the possibility that Ward was the collector.

In his article ". . . On 12 N[ew]. Sp[ecies]. of Plants from Illinois, &c.," Rafinesque (1832)[729] wrote that "they were chiefly discovered in 1818, or given me since by Dr. Muller and Dr. Ward." Although this sentence is hopelessly ambiguous, the person responsible for the eight Illinois plants collected in 1818 may well have been Rafinesque himself.

When Rafinesque (1824)[464] first published the genus *Lophactis*, he mentioned only that the plant was very rare in Kentucky and that "it has been found near Harmony on the Wabash by Dr. Miller" [Müller]. When he wrote about the plant 8 years later, Rafinesque (1832)[732] redescribed it as *Lophactis uniflora* (=*Silphium* sp.) and added: "I noticed in 1818 this plant on the Wabash, but out of blossom[;] in 1821 Dr. Ward brought me a perfect [flowering] specimen from White R[iver]. Indiana." Rafinesque is not known to have visited this locality, but Ward supposedly obtained the Delaware pictographs there.

In his list of the 12 new Illinois species, Rafinesque (1832)[729] provided the dates when he first obtained them. Assuming that Rafinesque himself was responsible for the specimens collected in 1818, and that Müller was responsible for at least one and no more than three of the remaining plants collected in subsequent years, then Rafinesque's cumulative attributions would indicate that Ward was responsible for a total of as few as three and for no more than five of Rafinesque's "new species." In 1833, Rafinesque listed Ward as one of three contributors to the collection listed in the "Florula Centralis or Illinoensis."[811] Since Rafinesque provided no further information on collectors and localities in this publication, it is impossible to adjust the figures already suggested as to the extent of Ward's contribution to Rafinesque's herbarium. It might be noted, however, that the three plant names *Collinsia purpurea, Plantago gonophylla,* and *P. atrofusca* occur both here and in the 1832 list. As noted earlier, the *Collinsia* is more likely to have come from Müller.

Rafinesque (1833)[749,788] included Ward in a list of "Professors and Doctors" who had "added to my N. Amer. herbals." And then in his *New Flora and Botany of North America, Vol. 2*, Rafinesque (1837, pp. 9, 13)[868] mentioned Dr. Ward twice, first in a list of botanical friends and collectors from whom he had "received much help by gifts or exchanges of specimens, new facts and observations," and then in a list of the botanists "who have fallen victims to their zeal in arduous travels, or from diseases contracted by their labors." This last item of information would seem to coincide with Rafinesque's (1836)[858,859] reference to "the late Dr. Ward of Indiana" as the source of the Delaware pictographs.

As mentioned earlier, none of the candidates suggested by researchers is a perfect match for "Dr. Ward" as described by Rafinesque. In the standard critical edition of the *Walam Olum*, Weer (1954) presented what was known of the biography of Dr. John Russell Ward (?–1834), who resided in Kentucky at Cynthiana, Harrison County, as early as 1808, and then at Carlisle, Nicholas County, from 1816 to 1829. Rafinesque wrote in his *Life of Travels* (1836b, p. 71)[863] that in 1824, "My friend Mr. Ward took me to Cynthiana in a gig, where I surveyed other ancient monuments, and found a fine locality of fossils." A writer less cautious than Weer might have assumed that this "Mr. Ward" and the Nicholas County physician were one and the same. However, Boewe (1987b) has presented evidence to suggest that the gig-driver was the Lexington Episcopal clergyman John Ward, the brother-in-law of Rafinesque's late patron John D. Clifford. This individual may well be the same Ward of whom Rafinesque, as superintendent of the Transylvania Botanical Garden, would have occasion to write in 1825, "Received many presents of seeds and plants from Messrs. Clay, Ward, Fowler and Megowan" (Harrison 1913; Weer 1954), although the generic term "Messrs." might possibly have subsumed the more specific title "Doctor." From Carlisle, Dr. John Russell Ward moved to Missouri, where he died at Fulton, Callaway County.

Another suggestion is William Ward, from Mason County, Kentucky, who was a medical student at Transylvania University from 1823 to 1826 and earned his medical degree just 2 months before Rafinesque permanently left Lexington (Boewe 1987b). Little else is known of William Ward, and Boewe was unable to find specific instances of direct connections or written communications with Rafinesque.

Malthus A. W. Ward (1794–1863) would be the ideal candidate were it not for the fact that Rafinesque described his "Dr. Ward" as "late" in 1836. Various attempts have been made to read this adjective as referring to Ward's place of residence, that is, as "lately" of Indiana, or perhaps as referring to Ward's profession, that is, as no longer practicing medicine, but Rafinesque's (1837)[868] allusion to Ward as one of the botanists "who have fallen victims to their zeal in arduous travels, or from diseases contracted by their labors" strongly suggests that Rafinesque believed him to be dead.

According to Barlow and Powell (1986), Malthus Ward

> . . . was born at Haverhill, New Hampshire, in 1794. After studying under a local physician and attending the Medical Institution at Dartmouth College, he settled in Kittanning, Pennsylvania, in 1815, then moved to Pittsburgh in 1816. In 1819 he located to Hindostan, a pioneer Indiana village on the east fork of the White River near the contemporary town of Shoals, in Martin County [where he probably remained until late 1822]. Ward's lengthy and detailed letters written during this period reveal his interest and erudition in both botany and zoology. His interests in these two sciences developed during his student days from 1812 to 1814 at Middlebury College, Middlebury, Vermont.

After receiving his medical degree at the Medical School of Maine in 1823, Ward practiced medicine and continued his interest in botany and natural history throughout the remainder of his life. He lived at Salem, Massachusetts, from 1823 to 1832 and at Athens, Georgia, where he was appointed professor of natural history. He died in Athens in 1863 (Barlow and Powell 1977, 1978a, 1978b, 1986). Malthus Ward appears never to have mentioned Rafinesque in his letters or manuscript notes (Boewe 1987b).

Rafinesque very possibly interacted with two or more Wards, at least one from Kentucky and one from Indiana, whose discrete identities were lost when he failed to record anything other than their last names. This speculation becomes all the more plausible by noting that references to the various candidates provide no indication that any one of them had both a Kentucky connection and an interest in floristic botany, the isolated exchange of 1825, as cited by Harrison (1913), being horticultural rather than botanical. When acknowledging other persons, Rafinesque characteristically used their last names only, and therefore the name "Dr. Ward" could easily, but misleadingly, apply to more than one person.

* * *

The relationship between Rafinesque and Dr. Daniel Drake (1785–1852), early Cincinnati's preeminent physician, educator, and scientist, was not a particularly productive one. By 1818, at age 33, Drake held undisputed leadership as a scientist and botanist of the Ohio Valley. He was the first Ohio Valley resident to publish information on local vascular plants in his books, *Notices Concerning Cincinnati* (Drake 1810–1811) and *Picture of Cincinnati and the Miami Country* (Drake 1816). On 8 May 1818, in Cincinnati, he was apparently the first to give public lectures on botany, a venture that proved to be of great interest, with 40 subscribers enrolling in his initial course (Horine 1961, p. 153). Thomas Nuttall visited Drake at Cincinnati in 1816 and 1818 and later referred to him as "one of the most scientific men west of the Allegheny Mountains" (Nuttall 1821). Drake was also involved in organizing Cincinnati's Western Museum Society, established in 1818.

Rafinesque's letter of 8 July 1820 was his earliest known contact with Drake (Horine 1961, p. 141). Addressed to Drake as the secretary of the Western Museum Society, the letter offered marine shells, botanical specimens, and publications in exchange for mounted birds and quadrupeds of the West. Although Drake reportedly replied on 29 August, the assumption is that nothing came of the proposal, for Rafinesque wrote in a letter[413] of 7 January 1821 to Bory St. Vincent, in an apparent reference to these kinds of scientific institutions, "Many of their puffs are mere tricks, for instance, they have established

a Museum, which has issued proposals of exchange; but when applied to, they had nothing to give, but were very greedy to receive!" In this same letter, Rafinesque addressed himself more specifically to the subject of Drake by saying that he "has shown himself an author of capability in his first work called *Picture of Cincinnati*; although that work is not free from defects and even errors: but he has not published anything since, except small rhetorical pamphlets; he aims at knowledge however, and if he does not know how to reach it, it is perhaps because he has a share of the unfortunate shortsight."

Drake's biographer, Emmet Field Horine (1961, pp. 141–144, 195–196), described other non-scientific interactions and caustic comments exchanged between the two individuals in literary publications. Horine pointed out that, although Drake taught materia medica and botany in the Medical Department at Transylvania from 1823 to 1825, he seems to have had little contact with Rafinesque, who taught in the Academic Department. Both men were members of the Kentucky Institute and read papers[454] before that scientific and literary organization in Lexington in 1823.

Drake was a subscriber to Rafinesque's short-lived Transylvania Botanical Garden in 1824 (Peter 1905, p. 38). Upon leaving Transylvania to return to Philadelphia in 1826, Rafinesque passed through Cincinnati, sought out Drake, and visited Joseph Dorfeuille's Western Museum with him on 9 May (Rafinesque 1987, p. 19). Rafinesque's final mention of Drake came some years later, in the passing acknowledgements at the beginning of the *Medical Flora* (1828).[554]

* * *

In an account of his botanical collections,[788] Rafinesque also noted that several ladies, including Mrs. Mary (Austin) Holley, wife of Transylvania University President Horace Holley, and Miss Jane Short, half-sister of Dr. Charles W. Short, contributed to his herbarium. In a letter of 15 June 1820 to Dr. Short, Rafinesque wrote from Lexington: "Your sister gave me sometime ago a fine Trillium collected near Hopkinsville, which differs from T. sessile by having petiolated leaves, yet it is not the Tr. petiolatum of Pursh. I should like to have more of it." He described it further as "a beautiful species differing from Tr. sessile, by its petiolated leaves, reflexed calyx and pale purple petals," as he commented in a letter[391] of 1 December 1820 to DeCandolle. The plant on which Rafinesque based his *Trillium reflexum* was a specimen he had obtained from Jane Short (1803–1841), who in 1839 married James Weir of Greenville, Kentucky. Rafinesque's letter to DeCandolle was published in 1821 in his *Western Minerva* (Rafinesque 1820b) with the identical diagnosis as in the letter. Fox (1900), in his synopsis of Rafinesque's *Western Minerva,* quoted Rafinesque's diagnosis verbatim, thereby validating the plant's name. Because the *Western Minerva* was suppressed during printing and no copies were placed in circulation, it would follow, according to an item in the *Botanical Gazette* (Anonymous 1900) and according to the *Code of Botanical Nomenclature,* that valid publication of Rafinesque's *Trillium reflexum* was not attained until his diagnosis appeared in the article by Fox (1900). The taxonomic status of this Rafinesque species in the flora continues to remain in doubt, as this entity was not discussed in the most recent study of the sessile-flowered trilliums (Freeman 1975).

* * *

A member of one of the most aristocratic families in early Kentucky, Dr. Samuel Brown (1769–1830) could claim to be the first professor of medicine west of the Alleghenies, having been named to the chairs of surgery, anatomy, and chemistry and pharmacy at Transylvania in 1799 (Peter 1905). However, medical classes at the University did not meet on a regular basis for another 20 years. Dr. Daniel Drake thought enough of Brown's talents to offer him a professorship at Cincinnati's newly founded Medical College of Ohio in 1818, but Brown chose to remain in Lexington, where he served as Professor of Theory and Practice of Medicine until his retirement from public life in 1825 (Horine 1961, pp. 157-159, 206).

Brown's interest in botany appears to have been mostly with useful plants, especially commercial ginseng. Ewan (1967a) summarized Brown's botanical correspondence with Thomas Jefferson, who described him as

"more conversant in Botanical researches" than Jefferson.

Rafinesque must have befriended Brown at a fairly early date, as indicated by the fact that in 1818 he listed Brown as one of the residents of Lexington through whom plants might be forwarded to him while on his first trip to Kentucky (Perkins 1938). He acknowledged Brown on at least three occasions. In 1821, in an article[401] in the *Western Minerva*, Rafinesque wrote:

> Dr Samuel Brown having procured and shown me the plant which is said to occasion in Kentucky the Milk Fever, I have ascertained that it is the *Euphorbia peploides* (*E. peplus* of Pursh, not Linnaeus), which is not uncommon on the cliffs and rocky situations in Kentucky. When eaten by cows through chance, it gives them a fever, and their milk becomes poisonous, producing the milk fever in those who drink it.

Rafinesque expressed his indebtedness to Brown, among others, in his *Medical Flora* (1828).[554] In 1830, in his *American Manual of the Grape Vines*,[558] Rafinesque named Brown in his inventory of Americans who were attempting to practice viticulture on a large scale.

GROWTH OF RAFINESQUE'S WESTERN HERBARIUM

Rafinesque's zeal for field botany is readily shown in the rapidity with which he collected plants and assembled an herbarium of western plants. The growth of his herbarium is well documented in his letters to Zaccheus Collins (Pennell 1942) and Charles W. Short (Perkins 1938) as well as in his publications. The first indications of this effort are contained in the letters he wrote to Collins in the summer of 1818, during his first trip into the Ohio Valley. On 12 August 1818, while visiting Audubon at Henderson, he commented: "In Botany, my discoveries are really extensive, I have collected or seen nearly 600 sp[ecies] of plants within 2 months, among which are about 20 N[ew]. Sp[ecies]." Writing to Short on 27 September 1818 from Lexington, he added: "And in Botany I have collected more than 600 sp. of Plants of which one tenth part at least are new." In his first published paper[270] on western botany, a letter to editor Samuel L. Mitchill, dated 20 July 1818, Rafinesque wrote:

> The vegetation of the Western States has some peculiar features—the most striking is its monotony, a few species being spread by millions over large tracts of country, while but few spots rich in a variety of plants are to be met with. I have collected, however, a rich herbarium both on the Ohio and in crossing the Alleghany mountains.

In a later published letter,[272] dated 5 October 1818, Rafinesque added: "I have collected about 700 species of plants in the western states, while only 200 had been stated to be found there." On 25 August 1823, Rafinesque noted in a letter to Collins that he had "collected nearly 2,000 specimens" of western plants that season. A memorandum at the Academy of Natural Sciences of Philadelphia, dated 1 January 1824, reveals that his herbarium of North American plants consisted of 5,000 species and 23,050 specimens (Pennell 1942, p. 29; Merrill 1949, p. 34). In 1826, the year in which he left Lexington, Rafinesque wrote in a letter of 12 January to Collins: "I have the finest herbarium in the United States, upwards of 25,000 specimens." This figure is in agreement with a later report[788] in his *Herbarium Rafinesquianum* (1833), where he stated: "My own herbals contain now about 4,200 N[orth]. American species, 5,000 varieties, and 25,000 specimens, nine tenths of which have been collected by myself, and after exchanging or selling already 10,000 specimens."

While living in Kentucky, Rafinesque also built an extensive herbarium of foreign plants. He boasted of this achievement in an article[441] in the *Kentucky Gazette* for 4 April 1822:

> My rich herbarium has . . . been lately increased with about 3,000 foreign specimens, and this is I believe the first instance of such valuable vegetable collections being brought to the western country, where I hope that it may become the foundation of the most extensive botanical collection in the United States, if it is not so already.

He credited large numbers of specimens to the following sources: 500 specimens of French plants from Prof. A.P. DeCandolle of Geneva, 810 specimens of English plants from Adrian Hardy Haworth (1788–1833) of London, 300 species of European plants from William Swainson of Liverpool, 200 from Prof. William J. Hooker (1785–1865) of Glasgow, several hundred from the Imperial Museum of Vienna, and 748 German plants from "Prof.

Schultze" of Augsburg, probably Josef August Schultes (1773–1831), Professor of Natural History and Botany at the University of Landshut in Bavaria from 1809 to 1831 (*fide* Charles Boewe, pers. comm.). An item by "Reporter" (1823) appeared in the *Western Monitor* for 30 December 1823, and contained the notice that Dr. C.G.D. Nees von Esenbeck (1776–1858), Professor of Natural History in the University of Bonn, Germany, had sent to Rafinesque "a splendid collection consisting of 500 plants from Egypt—100 from Palestine—700 from Greece and Crete—600 from Bohemia—and 600 from Austria and Hungary, making in all 2,500 specimens." In the article in *Herbarium Rafinesquianum* (1833),[788] Rafinesque added: "My foreign herbals contain about 3,000 species and 8,000 specimens from Europe, Asia, Africa, Polynesia, South America and Mexico."

Rafinesque's entire herbarium of domestic and foreign plants consisted of 12,745 species and 37,740 specimens, as recorded in his memorandum of 1 January 1824 (Pennell 1942, p. 29; Merrill 1949, p. 34), and about 10,000 species and 40,000 specimens as noted in his *First Catalogues . . . of the Botanical Garden of Transylvania University . . .* (1824).[468] Toward the end of his life, Rafinesque estimated in his *New Flora and Botany of North America* (1836–[1838])[568] that his herbarium totaled about 50,000 specimens.

After he left Lexington, Rafinesque's herbarium was placed in storage in Philadelphia, where it remained from 1827 until the end of 1831. To his friend John Torrey of New York, Rafinesque wrote on 2 January 1832: "I find upon an average one tenth of the plants lost or Spoiled, but not many of my new or rare ones." He sought to enlist Torrey's help in finding buyers in New York for his specimens, and offered him a present of "*all my western Grasses* which I have put aside; they are 5 or 600 Species, mostly not determined; many may be new or very rare . . . . Meanwhile I will be very busy this Winter in surveying, labelling & putting up." Writing to the Moravian clergyman-botanist Lewis David von Schweinitz on 26 March 1833, Rafinesque complained of having to label his plants, saying that it "is a mechanical labor too great. It took me 2 days to label those 117 I sent you . . . ." These statements reflect the poor condition and lack of organization of Rafinesque's herbarium. As noted above, Charles W. Short had nothing positive to say about Rafinesque's specimens. Short did not hesitate to speak harshly of their quality, and perhaps some of these unkind comments reached Rafinesque through Torrey or other of Short's correspondents. Rafinesque tried to justify his situation and the quality of his specimens to Short, to whom he wrote on 5 August 1834, "You probably botanize in a good Carriage with a press for the plants while I had, like a Pioneer, to botanize on foot & carry my plants on my shoulders."

The history of Rafinesque's herbarium, like many facets of his life, is a pathetic one. The story has been told in detail by Merrill, in the introduction to the *Index Rafinesquianus* (Merrill 1949, pp. 33–37). During Rafinesque's later years and after his death in September 1840, his herbarium was stored in a garret, and rats destroyed part of it. In 1841, Elias Durand, curator of the herbarium at the Academy of Natural Sciences of Philadelphia, purchased the collection and proceeded to discard virtually all of the specimens as trash because they were damaged, not well pressed, very poorly prepared, or lacked labels with the names of the plants. Pennell (1942, 1945) and Stuckey (1971a, 1971b) have added other details of this history. Rafinesque certainly deserves credit for realizing the importance of assembling dried plant specimens for purposes of study and documentation even though he used very poor judgment in drawing conclusions from the specimens and did not give proper care to their maintenance and permanent preservation.

RAFINESQUE'S CONTRIBUTIONS TO THE FLORA, PHYTOGEOGRAPHY, AND IDEA OF PLANT SUCCESSION IN KENTUCKY

Rafinesque was the first individual to study thoroughly the plant life of Kentucky, the first state west of the Allegheny Mountains. Based on his extensive field work, his catalogues of the flora, outlines of phytogeographical regions, and discussion of plant succession in the limestone region were the first efforts at these kinds of botanical studies for Kentucky.

Writing Local Floras

A flora in its simplest form is a list of plants. In North America, the Rev. Manasseh Cutler

(1742–1823) of Ipswich, Massachusetts, was among the first to compose a local flora, for the plants of New England (Cutler 1785). Prior to 1800, the Rev. Henry Muhlenberg (1753–1815) of Lancaster, Pennsylvania, prepared floras of his neighborhood. Muhlenberg was convinced that knowledge of the entire flora of North America could best be assembled through the production of local floras by botanists working in their own neighborhoods (Youmans 1894, 1896). He had several followers who accepted this viewpoint and published their own local floras. Rafinesque visited Muhlenberg in Lancaster in 1803, but it is not known if Muhlenberg influenced the young, self-educated botanist to prepare local floras.

By his own admission, Rafinesque's first essays on North American plants, prepared in 1804, were catalogues[4] of the plants of the District of Columbia and the State of Delaware (Little 1943; Tucker and Dill 1989). But after submission and announcement for publication, these works were suppressed by Benjamin Smith Barton (1766–1815), editor of the *Philadelphia Medical and Physical Journal* (Barton 1805). Rafinesque's first published flora was his controversial *Florula Ludoviciana* (1817),[257] which he created by assigning scientific names to a list of common names of carefully described plants that the French clergyman and explorer Claude C. Robin (1750–1794) had appended as a "Flore Louisianaise" to a book in which he recounted his travels made during 1802–1806 along the Gulf Coast from present-day Louisiana to western Florida. Rafinesque thus named 30 "new genera" and 169 "new species." However, the naming of new taxa without having seen herbarium specimens or visiting the region to see the living plants was totally unacceptable to the larger botanical community, and for this armchair effort Rafinesque suffered severe criticism in letters and reviews (Mitchill 1818; Ewan 1967b; Stafleu 1968; Stuckey 1968). This publication became a major source of difficulty in his relationships with other botanists and editors of journals. As noted above, Rafinesque claimed to have written florulas of Missouri and Ohio, but apparently these were never published.

Early Catalogues of the Flora of Kentucky and the Ohio Valley

At the time of Rafinesque's arrival in the Ohio Valley, very little published material existed on the botany of the region. Dr. Daniel Drake had published floral calendars of the local spring plants and some notes on medicinal plants in his *Notices of Cincinnati* (Drake 1810–1811) and *Picture of Cincinnati and the Miami Country* (Drake 1816). In the latter book, Drake listed 61 genera and 102 species of woody plants growing in the Miami River Valley.

Rafinesque's first effort at preparing a local flora in the Ohio Valley may have been the "*Florula Louisvillensis*" (1819),[298] a list of 400 genera and 600 species of the plants growing in the vicinity of Louisville. Arranged alphabetically by scientific name with each corresponding common name, this catalogue appeared as part of a 255-page book describing the town of Louisville, written by Dr. Henry McMurtrie (1793–1865), first historian and promoter of the town (Thomas and Conner 1969). Some question exists as to who prepared the plant catalogue. In the *Western Review and Literary Magazine* for 1820, a reviewer inscribed only as "B." wrote that McMurtrie (1819) was "indebted to Rafinesque for most [of the names] . . . , or at least for their proper determination and classification." This reviewer has now been identified as the Reverend Mr. Birge (1797–1820), an Episcopal minister of Lexington, from a letter of 25 February 1820 by Horace Holley (Charles Boewe, pers. comm.). The reviewer criticized the work because some of the plants listed did not occur within 30 or even 50 miles of Louisville, others were listed twice under different names, and distinctions should have been made as to which ones grew in Indiana and which ones in Kentucky, or on the Silver Hills, in the Barrens, and on the flat plain surrounding the Falls of the Ohio River (Birge 1820). In 1821, in Rafinesque's *Western Minerva,* a notice[406] of McMurtrie's book appeared with the following statement: "An uncouth compilation full of errors; the new facts are so drowned in them that they cannot easily be perceived." This statement, which makes no specific reference to the "florula" itself, was probably written by Rafinesque even though it is signed "W.M." [=Western Minerva].

Rafinesque's "Florula Kentuckiensis" (1824),[468c] which encompassed the entire state of Kentucky, was one part of a 3-part brochure that described a projected botanical, agricul-

tural, and medical garden for Transylvania University. The "Florula" was indeed more than a simple list of plants. It was divided into three lists or sub-catalogues: (1) the principal trees, shrubs, and herbaceous plants; (2) useful plants, shrubs, and trees, whether medicinal, tinctorial, or economical; and (3) ornamental, fragrant, or "singular" plants, shrubs, and trees. The first group, which is the flora of Kentucky and the only group discussed in detail here, contained the new, rare, or peculiar plants to be offered by the botanical garden to the public, whereas the second and third groups were plants wanted for the garden. Rafinesque arranged the lists in the subcatalogues alphabetically, but in the first he divided the plants into two further groups of 43 species of trees and shrubs and 269 species of herbaceous plants. He noted all of the genera and species he had already named or was planning to name, with the abbreviation "Raf." or, if the genus was new, with "N. G. Raf." Of the 43 woody plants listed, he marked the genera *Cardiolepis* and *Cladrastis* and 17 species as new, and of the 269 herbaceous plants listed, he noted 10 genera and 154 species as new. He had already validly published some of the taxa and others were later validly published. Other new names are known only from this list as *nomina nuda* and have no validation in botanical nomenclature. Rafinesque did not provide names of the authors for the other taxa listed. The "Florula Kentuckiensis" can be considered a working list of those Kentucky plants that Rafinesque considered to be new to science, but it also provided an index to the scope of his floristic knowledge of the state after 5 years of residence there.

Rafinesque immediately criticized the next known flora of Kentucky, published by Short, Peter and Griswold (1833–1837), as "very deficient." He made this comment to Short in a letter of 5 August 1834, when he also wrote: "Are you aware that I printed one in 1820 [actually 1819] and another in 1824 where you will find many things you have omitted." Short's reply of 7 September 1834 showed some surprise, but he defended his own publication.

> I was certainly not apprized of your having published a catalogue of Kentucky plants, much less *two* of them; In that which we made out, and to which you refer, we did not pretend to give a perfect list, but one of those plants only which we had actually met with here, intended for the convenience of our correspondents in making out a list of their desiderata. Where are your catalogues to be had, I should like much to possess them?

In his letter of 25 October 1834, Rafinesque answered that his "Botany of Kentucky," [303] which was actually a phytogeographic essay although Rafinesque called it a "flora," had been published in the first volume of the *Western Review* in 1819, and that his "Florula Kentuckiensis" (1824),[468c] had appeared as a part of the circulars of the botanical garden in Lexington.

In a wider geographical perspective, Rafinesque was the first to take inventory of the prairie flora of central North America, in a work entitled "Florula Centralis or Illinoensis,"[811] which appeared as part of the *Herbarium Rafinesquianum* (1833)[786] and listed

> . . . 171 new plants from the Central Region, around the junction [the mouths?] of the Rivers Missouri, Illinois, Ohio, Wabash, Cumberland, Tennessee, and Arkansas, including West Kentucky and West Tennessee, East Arkansas and East Missouri, the South of Indiana and nearly the whole of Illinois. This Region is one of Plains and Glades called Western prairies and barrens, with some knobby hills: it has the same vegetation throughout, with many Southern and Western plants.

"Nearly all" of these 171 plants had been collected by Rafinesque between 1818 and 1826; "some" had been contributed by Drs. Müller, Short, and Ward.

Rafinesque's *Florula Wasiotana* (1833)[814] was a list of 33 "new plants" that he collected on the western slopes of "the Wasioto or Cumberland mts. of West[ern] Virginia, East Kentucky, and East Tennessee." Those names Rafinesque considered as new species have no validity, as no descriptions are associated with any of the names. The plant list was prepared primarily to advertise specimens for sale, at $7 per set.

Phytogeographical Regions of Kentucky

Although described as a floristic catalogue in his letter of 5 August 1834 to Short, Rafinesque's paper on the principal features of the "Botany of Kentucky . . ." (1819)[303] is in reality an outline of the major phytogeographical or vegetational regions of the state. He

divided Kentucky into four natural sections, or botanical regions, each distinguished by some floristic peculiarities. They were: (1) the fluviatile region comprising all the valleys and floodplains of the large rivers, a tract rich in species of trees; (2) the central region, comprising the limestone area between the valley of the Ohio River and the hilly ridges and knobs, a section remarkably poor in the number of plants, perhaps no more than 500 species; (3) the hilly region, comprising the hills and ridges dividing the waters of the Kentucky, Green, Licking, Cumberland, and Big Sandy rivers, a section rich in plants similar, so he had been told, extending to the Allegheny regions of Virginia and Pennsylvania; and (4) the barrens, comprising an open, extensive range, particularly in the western and southern parts of the state, with "islands" scattered among the central and hilly regions, destitute of trees, or with few scattered small ones, but thickly covered with a luxuriant growth of herbaceous plants. For each vegetational region, Rafinesque listed both the scientific and common names of representative or characteristic species as used in Kentucky. The most striking feature of the vegetation of Kentucky, compared with the vegetation of eastern United States, was, according to Rafinesque, the "propensity which many [herbaceous] plants and trees exhibit of growing in a social state, to the almost total exclusion of every other . . . . Many extensive spaces of ground are covered with one or a few crowded species, to the exclusion of many others . . . ." Rafinesque's letter of 25 October 1834 to Short largely repeated this phytogeographic outline, indicating that Rafinesque's ideas on the subject were basically unchanged since 1819 (Perkins 1938).

Rafinesque's efforts in describing the botanical regions of Kentucky were related to present-day vegetational studies in a recent paper by Bryant (1997). He considered Rafinesque's publication to be of great ecological significance but thought it unfortunate that Rafinesque did not engage in further study before the rush of settlement.

Rafinesque's 1819 paper on the "Botany of Kentucky . . ." was reprinted by Stuckey and Pringle (1997), as part of a larger study toward understanding Rafinesque's botanical work in the Ohio Valley. The Stuckey-Pringle paper focused on the comparative value of common names of plants appearing in pioneer floristic and vegetational studies published by naturalists and botanists in early 19th-century eastern North America, and those names applied to plants now. Without direct evidence, it can be inferred that Rafinesque's common names were provided to him by established residents or that he created them himself. To make Rafinesque's paper more useful to present-day botanists, Stuckey and Pringle supplied the currently accepted Latin names and added the common names now in use. Pringle wrote nomenclatural notes for 14 of the species.

As noted earlier, Short wanted the names of the Kentucky localities from which Rafinesque had obtained new plants, but he never received specific information on them. In his letter of 25 October 1834, Rafinesque replied: "Instead of the localities of some few plants, I am going to give you a general acc[oun]t of the best localities of Kentucky to my knowledge." Rafinesque probably could no longer remember sites for certain species, but he did remember well the general botanical geography, even though he had been gone from the state for 8 years. Referring to his paper[303] in the *Western Review* for 1819, Rafinesque again outlined the state's four botanical regions: (1) mountains and sandstone hills, (2) barrens and glades, (3) limestone basin, and (4) alluvial tracts, and he noted that each region had "peculiar rare plants." His description of each region mentioned the names of specific mountains, rivers, creeks, and towns and a few of the distinctive plants he recalled finding at these places. The treatment is another good general outline of the phytogeographic regions. It can be used to augment the earlier published paper and should aid the present-day geographer of Kentucky plants. From Short's point of view, the outline must have been less than he had hoped, since Rafinesque urged him to visit these places and find the rare plants himself, as well as more new ones. Rafinesque told Short that he could publish any of the sketch if he so chose, but "give me credit for it . . . ."

Plant Succession in the Limestone Region of Kentucky

Rafinesque briefly sketched the four botanical regions in a popular article, "The Cos-

monist–No. 8. On the botany of the western limestone region,"[441] published in the *Kentucky Gazette* for 4 April 1822. Because Rafinesque knew relatively more about the flora of this western limestone region, where the town of Lexington is located, he described its flora in greater detail than that of the other three regions. One of the most remarkable features was the paucity of species, of which no more than 600 grew within 15 miles of Lexington, while a similarly sized circle around Philadelphia would yield about three times as many, or 1800 species. Ferns, mosses, lichens, and members of the orchid and lily families also had few species. To compensate, he noted the large numbers of a few kinds of plants, such as grasses, deep-rooted herbs, and trees, each of which grew in "compact social clusters, covering many acres of ground, and with the utmost luxuriance." According to him, the vegetation of this region "may be ascribed [as] having been covered formerly with an extensive growth of Canes (*Miegia arundinaria*) [=*Arundinaria gigantea* (Walt.) Chapm.] forming almost a general canebrake under the forests, where but few plants could take a stand." He continued by stating that

> another remarkable feature . . . is the casual change of the prevailing [herbaceous] plants and trees upon many peculiar spots of grounds. It has been observed by the ancient settlers that the following plants have followed each other in succession in many plants [i.e., places] as the prevailing growth.
>
> The Canes, or *Miegia arundinaria*.
> The Butterweed, or *Eupatorium urticefolium* [= *E. rugosum* Houtt.].
> The Ironweed, or *Vernonia prealta*.
> The Nimblewill, or *Panicum dactylon*.
> The Hardgrass, or *Panicum glaucum*.
> the wild Camomile, or *Anthemis cotula*, &c.
>
> There is therefore a kind of natural perennial change of vegetation; when a species has exhausted the soil of a peculiar nutrition which it requires, it gives way to another for a series of years. &c.

These statements present a very clearly stated concept of ecological succession, and represent a very early, if not the first, appearance of this idea in the North American literature.

RAFINESQUE'S BOTANICAL WORK AT TRANSYLVANIA UNIVERSITY

Botanical Instruction

As the first professor of botanical science west of the Allegheny Mountains, Rafinesque was in a most enviable position to promote study of the science and to make known all aspects of the region's original flora. He came to this situation after visiting his long-time acquaintance John D. Clifford, who had a private museum of natural history in Lexington. Here Rafinesque became thoroughly occupied in study during a 3-week stay in early fall of 1818. Clifford, a local merchant, distinguished citizen, and trustee at Transylvania University, secured the professorship for Rafinesque during the winter of 1818–1819. Rafinesque accepted the appointment as professor of botany and natural history on 25 April 1819. Although the appointment was without salary, he had the privilege of free room, board, firewood, and candles at the University's Commons and was permitted to obtain whatever remuneration he could through paid subscriptions to his courses of lectures. Subscribers were to pay $10 for his courses, and he invited ladies and gentlemen from the community and students from the Academic and Medical departments in the University. To provide appeal to medical students, he added some lectures on medical botany to the botany course and lowered the price to $5. He also attached general botanical lectures to other lecture series, as, for example, those on theory of knowledge, the human mind, natural science, materia medica, and medical botany. He believed women "capable of higher education without risk to their delicate minds" (Boewe 1983) and so encouraged them to attend his classes in botany.

Rafinesque arrived at Transylvania University to begin work in the fall of 1819. He took his oath of office on 18 November (Bradford 1993, p. 242) and during December was much involved in writing his lectures, as documented from his letters to Collins and Short. An undated broadside,[949] outlining his two courses of 20 lectures each on natural history and botany, apparently circulated in the early autumn of 1819. The lectures were to be delivered between noon and 1 P.M., beginning the first week of November, the ones on natural history on Mondays and those on botany on Thursdays. Tickets for each course of lectures sold for $10. Much of this same information appeared in an advertisement[948] in the *Kentucky Reporter* for 6 October 1819, with the added note that the lectures were available not only to students in the Academic Department but

also to medical students and to ladies and gentlemen of the community. This announcement suggests that Rafinesque's courses were not a part of the university's regular curriculum because they were available to anyone willing to pay to attend them. For some unknown reason, as stated in a letter of 21 December 1819 to Short and later noted in the *Life of Travels* (1836, p. 61),[863] the course of lectures on botany was delayed until the spring of 1820.

The titles of the lectures on botany, as taken from the broadside, are listed below:

1. Introductory. On Botany in general and its uses.
2. On the organs of Plants, Roots, Stems, Trees, &c.
3. On the organs of Leaves.
4. On the organs of Flowers.
5. On the organs of Fruits and Seeds.
6. On the physiology and anatomy of Plants.
7. On Vegetable elements & productions.
8. On the qualities & diseases of Plants.
9. On Agriculture & Horticulture, or the cultivation of Plants.
10. On the Geography of Plants.
11. On botanical history, writers & works.
12. On botanical classifications.
13. On the Linnean System.
14. On the natural arrangement of Plants.
15. On the properties of Plants.
16. On botanical names or nomenclature.
17. On the Botany of North America.
18. On the practical study of Plants.
19. Demonstration of American Plants.
20. Valedictory. On the means of cultivating & fostering the study & science of botany.

The spectrum of titles suggests a very full course covering the entire discipline in both its scientific and applied aspects. By today's standards, the outline of topics touched upon the broad array of a discipline now expanded in North American universities into many courses within a single department of botany or biology, or into several departments. Rafinesque's handwritten outlines and notes of 12 of these lectures survive in a small bound book, *Lectures on Various Subjects,* owned by the Academy of Natural Sciences of Philadelphia but on permanent loan to the library of the American Philosophical Society. Boewe (1983) edited and published the full text of Rafinesque's "First Lecture On Botany," with an introduction and notes, for the bicentennial commemoration of Rafinesque's birth, held at Transylvania University on 21 October 1983 (Rafinesque, Reynaud, and Reynaud 1984). In addition to serving as a souvenir of that occasion, the published lecture aids in the understanding of Rafinesque as a pioneer teacher of botany.

Rafinesque (1820a) aimed in his first lecture to convince his listeners that plants were pleasing objects for contemplation. He began by discussing human knowledge and reducing it to three kinds of science: (1) *rational,* arrived at through man's sensations within his mind without the need for natural objects; (2) *testimonial,* arrived at through man's experiences with other people who have made observations and statements; and (3) *experimental,* arrived at through man's own reasoning, experiences, and personal observations and through previous observations and testimonials of others. Natural history is a science that is derived from experimental knowledge; it is the individual history of any living body existing in the natural world. Rafinesque further defined the essential functions of living organisms. They are *nutrition,* which allows for plants to live and grow; *reproduction,* which allows for the perpetuation of the individual organism; and *death,* which comes to every individual organism. Similar kinds of organisms, however, collectively have a kind of immortality and continue to remain on earth. Plants, he stated, possess a kind of passive life, as compared to the active or mobile life of animals. His comparisons between plants and animals revealed many obvious differences, although many organisms, especially the "lower" ones, showed connecting links between the two groups.

Rafinesque continued by defining various terms that apply to plants. *Botany,* or *phytology,* is the name given to the "entertaining study of all the vegetable bodies; and of all their numberless faculties, properties, and phenomena." Mankind is indebted to plants for food, vestments, and dwellings, "besides the remedies which relieve our diseases." Botany is studied both for amusement or for instruction in the usefulness of plants to mankind; Rafinesque gave examples of plants in both of these groupings.

As an academic study, botany is further di-

vided into other sub-units, as follows: (1) *Taxonomy* refers to the alphabet of the science, the laws of order, or the classification system, the Linnaean System being the preferred system of organization by botanists at Rafinesque's time. (2) *Glossology* refers to technical language used in describing plants. (3) *Nomenclature* refers to the naming of plants. (4) *Synonymy* refers to the names given by different authors to the same plants. (5) *Phytography* refers to the descriptions of plants composed of the terms from Glossology. (6) *Photocreny* refers to the practical use of plants through the investigation of their qualities and properties. They provide

(a) the food and drink for mankind;
(b) clothing, buildings, fuel, furniture, weapons, dyes, and many others;
(c) remedies or palliatives for human disorders; and
(d) food for domestic animals and wild animals.

Rafinesque concluded that botany can be studied "as an amusement or as a temporary occupation" and that it should be accomplished through "zeal and satisfaction."

Rafinesque continued to give lectures on natural history and botany, but he also taught French, Italian, and Spanish. In 1821, he began presenting public lectures, in Lexington, on botany, "elements of useful knowledge," geometry, map-drawing, phrenology, and craniology, as noted by Dupre (1945, pp. 16, 30–33) from announcements in the *Kentucky Reporter* and from dated manuscripts of selected lectures. Rafinesque, however, was not the first to present public lectures in botany in the Ohio Valley. That enterprise, as noted above, had been inaugurated in Cincinnati by Daniel Drake in May 1818 (Horine 1961, p. 153).

At Transylvania University, the curriculum was divided among the Academic, Medical, and Law departments. Rafinesque, whose appointment was in the Academic Department, sought the Medical Department's chair of materia medica and medical botany when it became available. As noted by Rafinesque in the *Life of Travels* (1836, p. 65),[863] President Horace Holley (1781–1827) denied him that opportunity because he did not have a medical degree. Rafinesque persisted, as noted in letters of 1 and 12 February 1822 to Short, by offering to develop a botanical garden and museum for the University, on the condition that it would annex his existing professorship to the Medical Department. The chair of materia medica and medical botany went to Dr. Daniel Drake, who had already held it in 1817 and 1818 and now occupied it again from 1823 to 1825, after which he was transferred to the chair of theory and practice and to a simultaneous deanship of the Medical Department until his resignation in 1827. Dr. Charles W. Short was elected to the chair of materia medica and medical botany in August 1825 and continued in that position until his resignation in 1837, simultaneously serving as dean from 1828 until 1837.

By some unknown arrangement, Rafinesque gave a course on medical botany to a class of medical students in 1822. On 1 February 1822, he wrote to Short that he was currently delivering a course on medical botany and that he would give another course on botany in the spring. In an advertisement[448] in the *Kentucky Gazette* for 17 October 1822, Rafinesque invited medical students to attend his course of lectures on medical and systematic botany to be given twice a week at convenient hours during the coming medical session. In his *Life of Travels* (1836, p. 73),[863] he wrote that his first course of lectures on medical botany began in the winter of 1823–1824 and included an exhibition of specimens of useful medicinal plants he had obtained through his own collecting and from friends or pupils from Missouri, Illinois, and Arkansas. By employing this technique of demonstration and display, Rafinesque was pioneering in the methods of teaching materia medica and botany. In February 1824 he was lecturing on botany to 108 medical students. His medical lectures continued through the winter of 1825–1826.

The lectures of Drake and Short were also held during the winter months and coincided with those of Rafinesque, and yet no evidence is available to reveal that Rafinesque was in contact with these individuals at those times. He had earlier corresponded with both gentlemen, had botanized with Short as they traveled between Lexington and Cincinnati in 1821, and had visited Short at his home in Hopkinsville in 1823. Even though much has been written on the association of Rafinesque with Transylvania University's Academic De-

partment and on the history of its distinguished Medical Department, little if any interaction appears to have existed between these two components of this great university (Peter and Peter 1896; Peter 1905; Dupre 1945; Sonne 1939; Jennings 1955; Wright 1975; Gobar and Hamon 1982). Apparently these departments were largely content to ignore each other during the 1820s but began to function cooperatively in the 1830s, after Transylvania's finest days were past (Christianson 1981).

Little is known of the quality of Rafinesque's lectures and of the response from students and townspeople to the lectures. No reportorial or editorial notices of them appeared in local newspapers (Call 1895, p. 46). Call did quote from a letter by George W. Jones, one of Rafinesque's former students, who wrote that Rafinesque "often lectured to the students in the College and in a most entertaining manner to the great delight of his audiences," and who then proceeded to describe an entertaining lecture about ants (Call 1895, p. 43). Another letter came from Johanna Peter, daughter of the Robert Peter (1805–1894) who served in the Medical Department as librarian, teacher of chemistry and pharmacy, dean, and writer of its history. She described Rafinesque's lecture room as "the scene of the most free and easy behavior, made possible by the total absorption . . . of the lecturer, who was always totally oblivious to his surroundings when occupied with his favorite pursuits." Those pursuits included botany, of which "he was an enthusiast" (Call 1895, p. 63). Judge Belvard J. Peters, of Mount Sterling, Kentucky, must have considered Rafinesque a kind of "ecologist." He wrote: ". . . I think Botany was his favorite study. He spent much time in the mountains of Kentucky . . . investigating the quality of the different soils and their adaptability to the production of various plants, vegetables, etc." (Call 1895, p. 67).

Little is known of any students who may have studied botany with Rafinesque. Although no records of contacts have been located, Josiah Hale (ca. 1791–1856), a Louisiana botanist and graduate of the Medical Department of Transylvania University in March 1822, is supposed to have been a private pupil of Rafinesque's, and "imbibed from him his passion for botany" (Ewan 1977). In articles[391,401] in the *Western Minerva,* Rafinesque also acknowledged receiving information on the medicinal properties of two liliaceous plants "communicated by Mr. Crockett, a medical student." Several valuable additions to his herbarium were also made by a "Mr. Crockett." This individual may have been Dr. G.J.H. Crockett of Hendersonville, Scott County, Kentucky, who purchased one share of stock in the Transylvania Botanical Garden and who later practiced medicine at Frankfort, where he was located when Rafinesque thanked him for information used in the *Medical Flora* (1828).[554]

The Transylvania Botanical Garden

Having been acquainted with botanical gardens at universities in Europe and with the private gardens of John Bartram and Humphrey Marshall near Philadelphia, Rafinesque desired to establish a botanical garden at Transylvania University. There he could assemble native and exotic plants for scientific study and practical research. His master plan for the project included several attached buildings for operation of a greenhouse, a museum, and a library. As described in his *Life of Travels* (1836, p. 72),[563] he went to Frankfort to solicit financial aid from the State Legislature. This aid was approved by the Senate but not the Representatives. Though disheartened by this action, he did not relinquish the idea of a garden, and so to divert his attention away from it, he was appointed Librarian of the University and Keeper of the Museum where the late John Clifford's natural history collections were kept.

Despite these political actions, Rafinesque assembled a group of university officials and private citizens of Lexington who petitioned the General Assembly for a charter for the establishment in or near Lexington of a public botanical, agricultural, and medical garden to be known as "The Botanical Garden of Transylvania University." The charter, approved on 7 January 1824 by Governor John Adair, provided for a corporation with stockholders, the details of which were explained in a published *Prospectus, By-Laws & Charter* (1824).[469] The garden would offer a number of advantages, according to the *Prospectus.* First, to the town of Lexington, it would be a pleasant and

healthful resort where citizens and visitors could take walks while observing living plants in an educational setting. Second, to the farmers of Kentucky, as well as all other citizens of the western country, it would provide a laboratory for experimentation with and improvement of fruit trees, garden produce, and grain-crops. Third, for the University's medical students, the opportunity would be available to study "the Medical plants of North-America and Europe, and acquire thereby an accurate knowledge of them; while the sons of our farmers will witness experiments and successful cultivation, receive instruction on the practical and scientific principles of husbandry and gardening, imbibing thus a taste for an improved cultivation of our bountiful soil." Fourth, the shareholders would receive financial dividends, for it was expected that "the single article of Opium, might it [be] needful, [could] be made to cover all the annual expenses of the garden."

The garden was to be planted with trees, shrubs, and herbaceous plants procured by collection, exchange, or purchase. Among them were fruit trees, useful ornamental or medicinal plants, and economic vegetable and grain crops. The entire grounds, not to exceed 25 acres at first or 50 ultimately, were to be divided into an ornamental garden, orchard, shrubbery, groves, nursery, medical and agricultural garden, meadow, and park. The structures mentioned were houses, halls, galleries, stores, cabins, walls, fences, gates, pavements, cisterns, wells, fish-ponds, aviaries, and embellishments. A museum would house dried specimens of all the plants cultivated in the garden, and a library would include books on agriculture, gardening, domestic economy, veterinary medicine, botany, mineralogy, and natural resources. Lectures and practical demonstrations were to be given on these subjects. Students and visitors had access to all of these facilities although they were to be charged a small fee of 25 cents per day or one to five dollars per year for daily access to it. At specified times, plants would be sold for distribution throughout the state or country.

The by-laws section of the *Prospectus* (1824)[469] of the Transylvania Botanic-Garden Company provided for the formation of a Board of Directors, to which Dr. William H. Richardson (?–1845), professor of obstetrics in Transylvania's Medical Department, was named as president, and to which Rafinesque was named as secretary. The by-laws also provided for capital stock, sold by subscription at $50 per share, with payments made in $10 installments over a period of 4 years. In his handwritten *Subscription Book* (1824b), Rafinesque included the date, signature, and number of shares purchased by each shareholder. Thirty of the subscribers were residents of Lexington, and 37 were from elsewhere in Kentucky. Rafinesque purchased five shares, President Holley one share, and Professor Richardson three shares. Ohio Valley botanists whose names appeared on the list were Dr. Daniel Drake, who was subscribed for two shares by Richardson, and Nicholas Longworth (1782–1863), a wealthy Cincinnati lawyer turned horticulturist, who was to pay for his six shares in "trees, plants & seeds." The book records that 97 shares were sold. In a public notice,[455] Rafinesque calculated that the sale of 100 shares would put the institution into operation and that the stock would become profitable because it was "contemplated to cultivate in the garden, many valuable products suitable to the climate, such as Opium, Castor Oil, Ginseng, Vines, Madder, &c. besides all kinds of Fruit trees, Ornamental trees and plants, medical roots, &c."

Rafinesque was to be superintendent and director of the garden. As defined in the by-laws,[469] the superintendent "shall act as manager of the garden, secretary and clerk of the board of directors, architect of the buildings and improvements, keeper of the museum, librarian, professor of the Institution, agent for collecting subscriptions and collector of objects for the garden." He also had to hold five shares of stock and could be removed from the position only by vote of three-fourths of the Board of Directors.

To advertise and explain the work of the garden, Rafinesque had printed a 24-page pamphlet titled *First Catalogues and Circulars of the Botanical Garden* (1824).[468] It consisted of three parts: first, a three-page "Circular of the Directors" written in both English and French, which described the contemplated activities of the garden and requested donations of living plants and other gifts for the museum and library; second, a three-page "Circular of C. S. Rafinesque," also in English and French,

to his friends and correspondents in America and Europe, describing his own professional pursuits and including places traveled, numbers of new species discovered and described, number of plants in his herbarium, and the extent of his manuscripts written or published; third, the "Florula Kentuckiensis," being a catalogue of the principal trees, shrubs, and herbaceous plants of Kentucky, as described above. This catalogue consisted of three subcatalogues. The first was the checklist of the plants of Kentucky, as described earlier; the second, an alphabetical list of scientific names of the useful plants, shrubs, and trees medical, tinctorial, or economical wanted for the garden; and the third, an alphabetical list of scientific names of the ornamental, fragrant, or singular herbaceous plants, shrubs, and trees wanted by the Botanic Garden.

Another advertisement for assistance in developing the garden appeared in the *Kentucky Gazette* for 3 February and 10 February 1825 (Rafinesque 1825a), and listed six tasks that needed to be completed:

To Grub and plough about 7 acres of ground.
To pave about 60 square yards with flat stones.
To lay about 100 Cubic yards of a stone fence.
To put up a Board fence 7 feet high, around part of the ground.
To Cart Tan bark and other objects by the day by the load.
To procure and plant One Thousand young trees, Shrubs and Vines, from the woods.

An account of the early development of the garden was published by Harrison (1913), whose information was based primarily on minutes of meetings of the Board of Directors and on a manuscript journal of garden-related activities kept by Rafinesque (1825b). Harrison quoted from most of the daily journal entries from 15 March through 20 April 1825. Although published as if the entries were quoted verbatim, a comparison with the original text reveals that some words and phrases were omitted from Harrison's published version. The garden itself had become a reality by September 1824, with the purchase from one Joseph Megowan of a lot of about 10 acres on East Main Street, for $1000, payable in 5 years.

As recorded in the journal, Rafinesque (1825b), as superintendent, began developing the garden in the spring of 1825. On 15 March he engaged James Stuart as gardener for a month at $20, in addition to two other workers who were set to work pulling corn stalks. The journal gives a nearly daily account of clearing ground and planting trees, among which were cherries, weeping willows, locusts, and ashes. On 14 April, on an acre of ground, castor oil beans were planted and seeds of marsh mallows, chamomile, anise, and other medicinal plants were sown later. On 19 April, the day before the journal ended, Rafinesque received "200 valuable fruit trees and shrubs, and 27 pots from Mr. Nicholas Longworth," which were all planted the next day. In June 1825, Rafinesque departed from Lexington for Washington, D.C., leaving the garden in the care of Joseph Ficklin. During his absence, the garden must have been neglected, and financial difficulties arose when several subscribers did not pay their installments.

As noted in his *Life of Travels* (1836, p. 75),[563] Rafinesque made this trip east primarily to seek new employment, for he was finding it "impossible to struggle against the influence of the foes of science." Upon returning to Kentucky in the fall of 1825, he learned while in Frankfort that Holley had reassigned one of his two rooms to students and had heaped his books and scientific collections together in the other room. Holley also deprived him of his position as Librarian and his board at the College. Rafinesque then took lodging in the town. He abandoned the botanical garden "since the company would not support it properly, and thus it has been destroyed" (*Life of Travels,* 1836, pp. 78–79).[563] The minutes for March 1826 stated that the property was to be sold and the proceeds divided proportionally among those shareholders who had paid their installments. Rafinesque officially retained his professorship and gave his course of lectures on medical botany in the winter. In the spring of 1826, he left Transylvania University and made Philadelphia his permanent base of operation.

The Botanical Garden of Transylvania University was a grandiose undertaking for a small school on the western frontier of the United States and for a community that was not ready to understand, accept, use, and support it. It was another of Rafinesque's plans that was ahead of its time in that the ideas embodied in the undertaking became realities with the

development of agricultural and horticultural programs in the midwestern land-grant universities later in the century.

THE KENTUCKY INSTITUTE

The Kentucky Institute, a scientific and literary society organized in Lexington in January 1823, consisted initially of 24 members, half of whom were professors at Transylvania University and the others residents of the town (Venable 1891, p. 169). According to Rafinesque's *Life of Travels* (1836, p. 72),[563] this organization grew out of a literary club that had formed a year earlier. The institute met weekly, and at least one essay or paper was read and discussed at each meeting. An article[454] in the *Cincinnati Literary Gazette* for 13 March 1824 listed the titles of 13 essays and the names of the lecturers. Among these were three lectures by Rafinesque: "History and traditions of the Shawanoe [or Shawnee] Nation," "American Population," and "Geology of Kentucky." Daniel Drake had lectured on the "Influence of climate upon the character of man," and Horace Holley had also given two lectures. Holley was president of the organization, and Rafinesque served as secretary. Rafinesque gave another lecture entitled "On a new medical plant *Prenanthes opicrina* and a new kind of opium—*Opicrine*" before the Institute on 11 February 1824. This lecture[464] was published in the *Cincinnati Literary Gazette* for 10 July 1824. Rafinesque listed seven of his lectures, mostly on the subject of geography, in a *Catalogue* of his principal works sent to Thomas Jefferson on 15 February 1824 (Betts 1944). The lecture on *Prenanthes opicrina* was the only one on a botanical subject.

The Kentucky Institute was supposedly "the first scientific society formed within the state, and one of the first, if not the first, west of the Alleghenies" (Call 1895, p. 35). The organization had a short existence, but the date of its last meeting has not been learned. In the *Life of Travels* (1836, p. 72),[563] Rafinesque contended that his communications to the Kentucky Institute were "too learned," and thus he had "to become a Poet . . . ."

AN AMERICAN CALENDAR OF FLORA, AN UNFINISHED PROJECT

Rafinesque's total involvement with all aspects of botany in the Ohio Valley naturally resulted in some contemplated projects he never began or never completed. A very popular approach to botanical study during the first half of the 19th century, as noted from the large number of papers appearing in scientific, literary, and medical journals, was the preparation of floral calendars. These calendars recorded the phenological events in selected species on a daily, weekly, or monthly basis. Usually they were prepared during spring, when plants were breaking dormancy. Among items noted were the times when buds began to swell, leaves appeared, flowers opened, and fruits formed. The Rev. Henry Muhlenberg, who promoted the preparation of local floras, also suggested to Dr. Jacob Bigelow (1787–1879) of Boston that much information on the changes of climate in the United States could be acquired by recording information on the flowering times of common fruit trees and other plants. Bigelow issued a circular in which he requested that such observations be made during the spring of 1817 in various parts of the United States; a year later he published the results of these observations (Bigelow 1818a, 1818b). Rafinesque was unable to respond to Bigelow's request in 1817, but in *Silliman's Journal* in 1818 he published an article[275] recording the daily progress of vegetation from 20 February through 20 May of 1816 for the Philadelphia area. This paper had obvious usefulness in the fields of agriculture and gardening but was also a contribution toward a local vernal flora of the area and the much larger endeavor of compiling an "American calendar of flora."

Upon Rafinesque's arrival west of the Allegheny Mountains, the only known floral calendars for the area were those of Dr. Daniel Drake, who had published observations for the spring seasons of 1809 and 1815 in his books *Notices Concerning Cincinnati* (Drake 1810–1811) and *Picture of Cincinnati* . . . (Drake 1816), respectively. Rafinesque, intending to compile a floral calendar for the western states, begged information for it from Dr. Short, as recorded in his letter of 21 December 1819 from Lexington:

> Since you mean to watch your vegetation closely next year, I would advise you and even beg, that you may at the same time keep a kind of Journal of the progress of vegetation in the blossom'g, budding, foliation, &c of your plants, shrubs & trees, noticing when

> you shall first see in blossom every plant. I am going to keep the same kind of Journal here. I have already two such Journals from near Pittsburg & the banks of the Wabash kept by Dr. Muller; and from all those I hope to be enabled to draw a comparative Vernal calendarium of the Western States. You know that such Journals are very interesting in many points of view, & particularly in acquiring a comparative knowledge of climates. I invite you to begin yours in January, carry it as far as the end of May, and then throughout the whole year oc[c]asionally; if it is useful to know the first flowers of Spring, it is not less to know the last ones of Autumn.

Short probably never complied with this request, and Rafinesque's contemplated western floral calendar, although it may have been partially assembled or even written, has never been discovered in manuscript or listed as a published contribution.

WHY RAFINESQUE LEFT TRANSYLVANIA UNIVERSITY

Transylvania University professors Gobar and Hamon (1982, pp. 21–22) have attempted to summarize the reasons for which Rafinesque left the school in 1826. First, Rafinesque had hoped to establish a museum of natural history that would contain his extensive herbarium, but the Trustees would not fund it. Second, his prolonged absences from the campus, even though many of his excursions were to study and obtain specimens of plants and animals in the field, strained his relationship with President Holley, who, according to Rafinesque's perception, was not interested in supporting science. Third, his "foreign" demeanor made him an easy target for prejudice, and his personal faults did not help his reputation, already subject to mistrust and suspicion among his contemporaries. And fourth, as an author he was expansive and allowed his interest in novelty to lead him everywhere, creating the impression that he was at times a dabbler.

Huntley Dupre (1961, pp. 82–83), formerly a Professor of History at Transylvania, wrote the following of Rafinesque's leaving that university:

> Rafinesque felt himself to be unappreciated in Lexington and he became increasingly frustrated and disappointed. He felt that he was surrounded by foes of science, among whom he came to number President Holley . . . .
>
> William Leavey, a contemporary [and strong supporter of Holley], very likely reflected the opinions of the substantial citizens of the community in these words: 'Though learned and enthusiastic in Botany and the Sciences he professed, Professor Rafinesque was esteemed generally a visionary man. He was wholly unsuccessful in all his undertakings, and left Lexington with scarcely any means,—subscriptions were raised for him by friends on his leaving.'

SUMMARY

More has been written to describe and analyze the life and work of Rafinesque than of any other North American naturalist. Versatile, enthusiastic, eccentric, and egotistical he was; but "mad," "crazy," or "insane" he was not, as judged simply on the basis of his productivity. To his botanical contemporaries and their immediate followers, he was extremely controversial and thus for the most part they ignored him, but to the taxonomic botanists of the following century his contributions were objects that had to be evaluated. An individual with truly remarkable native mental ability and tremendous energy, he too frequently demonstrated a lack of appreciation of the realities of life. Rafinesque considered himself a traveler, and to him all of his scientific, linguistic, and historical pursuits were episodes within his larger life's journey (Boewe 1988). Of the sciences, he made it known that botany was his favorite, and he studied it more intensely and thoroughly than any of his other interests.

Everywhere Rafinesque went he discovered "new" plants. He sorted out minute morphological variations as indications of distinct entities. In an era in which naturalists often achieved recognition through describing what was new, Rafinesque wasted no time in making known his newly discovered plants. Consequently, he proposed new names for about 2,700 genera and 6,700 species—more than any other botanist. Simultaneously, he published discussions of new systems of classification, nomenclatural procedures, and processes of gradual changes in plants through time. Contemporary botanists and their immediate followers, led by Asa Gray, were quick to criticize Rafinesque and his innovative approaches. With reference to his new taxa, he was accused of not having made necessary comparisons with related or similar plants, of not having reviewed or cited the literature, and of not having the specimens to support

his conclusions. Yet examination of many of his publications, particularly his earlier ones, reveals that indeed he did make comparisons with related taxa. He did use the literature; citations are given to European and American authors and their works. Furthermore, he had written extensive reviews criticizing and making numerous corrections to eight of the major contemporary taxonomic botanical works of North America. He had the largest herbarium of any contemporary botanist, but it was lacking in organization; his plants were insufficiently labeled and apparently were not arranged into any usable system.

Rafinesque firmly believed that his designations of new taxa and his nomenclatural changes were valid contributions to science, but no botanist during his lifetime or for a century later could actually make the proper evaluations, as the world's flora was not sufficiently known and the definitive literature was not at hand. However, evaluation became necessary with the adoption, in 1867, and gradual refinement of the *International Code of Botanical Nomenclature.* It then followed that all of Rafinesque's proposed names had to be indexed, their descriptions read and compared with other taxa, and the specimens documenting these names located, if possible. This process of determining the validity and priority of plant names is often a frustrating task and will continue to be so. Surviving copies of Rafinesque's publications were few in number, widely scattered, or difficult to obtain, at least before reprinting processes became available. Nearly all of his herbarium was discarded as trash, and so it has been necessary for botanists to seek documentation from the herbaria of botanists to whom he sent specimens (Pennell 1942, 1945; Merrill 1949; Stuckey 1971b).

Rafinesque's botanical pursuits in the Ohio Valley are those of an active 8-year period during the middle of a very busy life. As the region's premier resident professor-naturalist, Rafinesque was the first to investigate all aspects of its natural history, but his botanical publications were the most varied and extensive. His discoveries of new plant taxa from the region were actually very few even though he named at least 612 taxa. For that series of poor judgments he deserves little praise. As the first resident professor of botany at a university in the Ohio Valley, he had the opportunity to expand and diffuse botanical knowledge through lectures, field work, and publications. Some may contend that he also failed in these efforts, but he must be considered a pioneer, some of whose accomplishments in these areas have not yet been fully evaluated or understood. He was the first to prepare checklists of the vascular-plant flora of Kentucky and of the prairies and barrens of the lower Ohio Valley. He was the first to outline and describe the phytogeographic regions of Kentucky and to list their characteristic species. He was the first to write an account of plant succession, now a fundamental tenet of plant ecology. Unfortunately, these innovative contributions, like so many of his publications, appeared in obscure scientific, literary, or popular journals, and thus they have been ignored, overlooked, and forgotten. Even Asa Gray (1841) admitted that he had not seen some of Rafinesque's publications printed in Kentucky, for they were marked as "unknown" to him. Rafinesque's efforts at establishing a botanical garden, although ending in failure, showed that he had the considerable foresight to plan and establish an elaborate facility for the general appreciation, study, and improvement of medicinal, horticultural, and agricultural plants. While he interacted personally with many of the botanists in the Ohio Valley, he begged and appropriated from them for his personal use all the information that he could obtain.

Rafinesque evidently lacked social skills and leadership qualities and had difficulty in working with associates. When editors of the more reputable scientific journals rejected his papers, when his own *Western Minerva* was "suppressed," and when his lectures before the Kentucky Institute were not well received, he claimed in all of these instances that the papers were "too learned." He admitted that his *Atlantic Journal* (1833)[783] "was too learned" for the common reader but boasted that it was "chiefly patronized by enlightened or learned men . . . ." This "reason" was a natural product of the self-centered personality that alienated so many of Rafinesque's associates. Many of his papers, however, contained new ideas that were considered unorthodox and were judged by some editors and publishers to be unworthy of publication. In many instances, Rafinesque's pioneering efforts were

not ready for acceptance, nor were his readers prepared to grasp or see the relevance of the new information being provided. Actually, in many respects he was distinctly ahead of the botanical writers of his time.

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The references cited are arranged into two groups:

The first group lists all of the cited papers that Rafinesque wrote and that have corresponding numbers in Fitzpatrick (1911) or in Boewe (1982). These numbers appear as superscripts throughout the text where reference is made to Rafinesque's own publications. A repetitive Boewe number is indication of a reprinting.

The second group lists all other citations. Specifically, it contains (1) papers and manuscripts written by Rafinesque that do not have assigned numbers and are not listed in Fitzpatrick (1911) or in Boewe (1982), (2) letters written to or by Rafinesque, and (3) secondary publications about Rafinesque and his work.

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Scientists of Kentucky

Medicine's Remarkable Brothers: Simon and Abraham Flexner of Louisville, Kentucky

SIMON FLEXNER (1863–1946)

It is rare to find within one family individuals as important to the sciences as were Simon and Abraham Flexner. The first of this talented duo arrived as the fourth child of Morris and Esther Flexner in Louisville, Kentucky, on 23 March 1863.[a] Starting out as a Jewish immigrant peddler, Morris Flexner eventually became a prosperous wholesaler in the lively river community, allowing him to give his children a reasonably sound education.

Simon Flexner (Figure 1) attended Louisville public schools until apprenticing himself to a druggist. His advanced studies began at the Louisville College of Pharmacy; he graduated there in 1882. He followed up his education by studying medicine at the University of Louisville. Calling it an "old-fashioned medical school,"[b] Flexner had little opportunity for formal laboratory work. Nonetheless, he obtained a microscope and began studying pathological tissues for physicians who frequented his older brother's pharmacy.

In 1890 he followed his younger brother Abraham's suggestion to remove to Baltimore and attend the progressive Johns Hopkins University. It was a decision that would change his life forever. There he met William Henry Welch (1850–1934), one of the founders of that university's outstanding medical school. Through Welch and his coterie of colleagues trained in the more advanced bacteriological laboratories of Europe, Flexner was introduced to systematic pathology and to the contributions of Robert Koch and Louis Pasteur's germ theory of medicine.

Simon quickly became one of Welch's prize students. In 1892 he received a fellowship and became first assistant in the pathology department. There he found the working conditions and collegial atmosphere fostered under Welch's watchful eye stimulating and conducive to independent study. "If a student who listened to him possessed the soul of an investigator," Flexner recalled, "sooner or later some problem would catch his imagination and all by himself he would get down to work. Then Welch would come to his assistance; a lead found, Welch kept the interest at white heat and guided the work into the most rewarding channels. He was alert and helpful, and always encouraging."[c] These early days with Welch at Johns Hopkins would foster a lasting friendship.

Under Welch's guidance Flexner blossomed into a mature scientific investigator. His education was furthered with a trip to Europe in 1893 where he was introduced to the work of leading scientists like the German pathologist Friedrich von Recklinghausen (1833–1910). Upon his return to the United States, Flexner again joined the pathology department at Johns Hopkins Hospital where by 1899 he achieved the rank of full professor.

That year saw the close of the Spanish-American War with official cession of the Philippine Islands to the United States on 6 February. This conflict resulted in 5462 deaths, only 379 of which were due to combat.[d] Dysentery, malaria, and typhoid fever devastated American troops stationed in Cuba, Puerto Rico, and the Philippines. Such losses prompted interest on the part of bacteriologists to investigate the etiology of these illnesses, and Flexner spent several months in Manila studying various pathogens for the newly created U.S. Army's board for the investigation of tropical diseases. His patient investigations were rewarded with the isolation of what he originally called "the Bacillus Dysenteriae," a lapse in nomenclature to which Welch quickly responded: "'I notice you usually write it the Bacillus Dysenteriae. It should be Bacillus dysenteria, leaving out the 'the', and having the generic names always begin with a capital, and the specific one with a small letter.' Welch was a purist concerning nomenclature. He consulted [Walter] Migula in this case and noted that he had given the name I used to Ogata's bacillus, and if he had done so before Shiga wrote, his name would be the one to stand,

Figure 1. Simon Flexner. Photo credit: The Alan Mason Chesney Medical Archives of the Johns Hopkins Medical Institutions.

but Migula wrote in 1900 and Shiga in 1898, so that the form Welch suggested was correct."[e]

Later this was further corrected by naming this Gram-negative bacterium *Shigella dysenteriae* after its rightful discoverer, Japanese bacteriologist Kiyoshi Shiga (1870–1957). Nonetheless, it is still often referred to as the "Flexner bacillus."[f]

Upon his return to the United States, Flexner accepted an offer to organize a pathology department at the University of Pennsylvania. While there he surrounded himself with young, promising students like Hideyo Noguchi (1876–1928), who began investigations into snake venoms and later isolated *Leptospira icteroides* as the bacterium responsible for yellow fever.[g]

In 1901 John D. Rockefeller had tentatively established what would become the Institute for Medical Research that would bear his name. Toward that end a director was sought. First Dr. Theobald Smith (1859–1934), who had performed pathfinding studies on Texas fever in cattle, was asked to head the Institute, but Smith declined, suggesting that the research facility envisioned by Rockefeller should encompass "the study of infectious diseases from all points of view." Smith added that his "interest for years in animal pathology . . . might give an impress to the work of the laboratory which might eventually arouse adverse criticism."[h] Welch, who had been involved in the Rockefeller Institute from the beginning, then wrote to his old friend Dr. T. Mitchell Prudden (1849–1924), who was vice president of the Institute's board of directors: "I think that Flexner is inclined to consider an offer such as we made to Smith, and if he could be secured I believe we could not find a better man."[i]

Flexner accepted the position in June 1902 and left his tenured faculty post at the University of Pennsylvania for the uncertainty of heading up a fledgling laboratory devoted solely to research. Although entering the new job with some understandable misgivings, he

led the Rockefeller Institute with his characteristic "vision and audacity."[j]

Here Flexner battled a host of human scourges. In 1906 he produced a serum against cerebrospinal meningitis that remained the treatment of choice until the development of sulfanilamide compounds (so-called sulfa drugs) in the 1930s.[k] Four years later he responded to a polio epidemic in New York City by successfully transferring the poliomyelitis virus between monkeys through their infected mucosa. As insignificant as this might seem, it represented a real breakthrough in the fight against polio. Not only did it prove that the virus could be found in nasopharyngeal mucosa, thus demonstrating the possibility of respiratory transmission of the disease, but this method of perpetuating the virus was later replicated less expensively in hens' eggs, leading ultimately to the development of protective polio vaccines in the 1950s. In addition, Flexner made great strides in epidemiology by observing "mouse-villages" where he carefully noted outbreaks of infection and the phenomenon of mass immunity response. He found that epidemics in the "village" could be triggered by the reintroduction of newly infected individuals or "susceptibles" into the group.[l]

Besides his research work, Flexner also edited the important *Journal of Experimental Medicine*, a task he took over from the founding editor William Henry Welch in 1902 and held for the next 15 years.

Furthering the work of the Rockefeller Institute for Medical Research remained Flexner's passion until his retirement in 1935. Shortly thereafter he began work on the biographical tribute to his mentor, William Henry Welch. Originally published in 1941, the book has been described as "a fitting final volume for his life history as [well as] for the great leader of his age."[m]

Simon Flexner married Helen Whitall Thomas in 1903. They had two sons: William Welch, who became a physicist, and James Thomas, who with his father co-authored *William Henry Welch* and went on to become an important historian of American culture.

Flexner's work in bacteriology and communicable diseases remains an important contribution to the fields of pathology and medicine. Upon his death on 12 June 1946, a long line of illustrious eulogizers including John D. Rockefeller Jr., Judge Learned Hand, and Dr. Herbert Gasser gave testimony to the keen mind and gentle spirit of Simon Flexner.

Among those who mourned the loss was Simon's younger brother Abraham. He too contributed mightily to the field of medicine, but in a very different and more controversial way.

ABRAHAM FLEXNER (1866–1959)

On 13 November 1866 Abraham Flexner (Figure 2) was born in Louisville into a home that stressed the importance of education and a strong work ethic. It is little wonder, then, that Abraham exhibited the same taste for learning and tenacity of purpose as his older brother Simon. In high school he sent articles to *The Nation* and by 1883 the precocious 17 year old was attending Johns Hopkins University, preceding his older brother Simon there by 7 years.[n] Abraham earned his bachelor's degree in just 2 years but not before he became familiar with William Welch, who was busy assembling the famous Johns Hopkins medical department.

In 1886 Abraham returned to Louisville where he regaled his family with stories of the brilliant, German-trained faculty at Johns Hopkins. He encouraged Simon to go to that university. By 1893 the enterprising young Abraham had started his own school in the bustling Kentucky river town, a venture that was successful enough to send his brother Jacob to medical school.

In 1905 Abraham Flexner sold his school and used the proceeds to attend Harvard. While in Germany for 2 years of additional study he wrote his first book, *The American College: A Criticism* (1908); in it he emphasized the importance of critical scholarship over the functional didactic techniques prevalent in America.

This early work formed the foundation upon which Abraham Flexner would build his most famous and enduring legacy. He was urged by Dr. Henry Pritchett (who was impressed by Flexner's first book) to initiate a comprehensive study of medical colleges across the country for the Carnegie Foundation. Flexner agreed; the result was the foundation's bulletin number four, the now famous

Figure 2. Abraham Flexner. Photo credit: The Alan Mason Chesney Medical Archives of the Johns Hopkins Medical Institutions.

(or infamous) *Medical Education in the United States and Canada* (1910) (Figure 3).

Flexner described in detail how in 1908 he began the arduous task of assessing the status of American medical education, and he left no doubt about his standard of comparison:

> Having finished my preliminary reading, I went to Baltimore—how fortunate for me that I was a Hopkins graduate!—where I talked at length with Drs. Welch, Halsted, Mall, Abel, and Howell, and with a few others who knew what a medical school ought to be, for they had created one. I had a tremendous advantage in the fact that I became thus intimately acquainted with a small but ideal medical school embodying in a novel way, adapted to American conditions, the best features of medical education in England, France, and Germany. Without this pattern in the back of my mind I could have accomplished little. With it I began a swift tour of medical schools in the United States and Canada—155 in number, every one of which I visited. I had no fixed method of procedure. I have never used a questionnaire. I invariably went and saw the schools and talked with teachers of medicine and the medical sciences and their students.[9]

There is little doubt that Flexner visited these schools with Johns Hopkins as the preconceived benchmark of comparison. There is also no question that the report was issued with the expressed purpose of eliminating a sizeable portion of America's degree-granting institutions. In Flexner's opinion the number

MEDICAL EDUCATION
IN THE
UNITED STATES AND CANADA

A REPORT TO
THE CARNEGIE FOUNDATION
FOR THE ADVANCEMENT OF TEACHING

BY
ABRAHAM FLEXNER

WITH AN INTRODUCTION BY
HENRY S. PRITCHETT
PRESIDENT OF THE FOUNDATION

BULLETIN NUMBER FOUR

576 FIFTH AVENUE
NEW YORK CITY

Figure 3. Title page of Abraham Flexner's *Medical Education in the United States and Canada* (1910).

needed to be reduced from 155 to 31 with an average annual graduating class for each school set at about 70.[p]

Flexner's chief complaint was against the large number of proprietary schools that had proliferated throughout the country during the 19th century. Operating essentially on a for-profit basis, these proprietary schools in his opinion represented a harmful "commercial treatment of medical education" that fostered crass promotional schemes abounding "in exaggeration, misstatement, and half-truths" designed to encourage enrollment and, ultimately, overproduction of physicians. Indeed he suggested that many of the deans of such schools "know more about modern advertising than about modern medical teaching."[q]

Although undeniably true, this sweeping indictment is overly simplistic and belies the historical context for the development of proprietary medical schools. "As of 1800," wrote noted medical historian John Duffy, "it was obvious that the number of graduates from the existing medical colleges was hopelessly inad-

equate for America's burgeoning population . . . . Under these conditions, the traditional concept of professional medical training had no validity. Entrance requirements were virtually eliminated, and the emphasis was placed upon practical skills and knowledge. Many of the professors were themselves products of the apprentice system, and they could see little value in laboratories or libraries. The caliber of these schools varied widely," Duffy added, "depending upon the educational background and conscientiousness of the professors, but . . . in even the best schools it was possible to acquire an easy degree."[r]

Nevertheless, Flexner was correct in characterizing the general state of medical education in the early 1900s as "ill manned and poorly equipped."[s] In some of the schools, conditions were bad almost beyond description. For example, Flexner described the independent Maryland Medical College thus:

> The school building is wretchedly dirty. Its so-called laboratories are of the worst existing type: the neglected and filthy room is set aside for bacteriology, pathology, and histology: a few dirty test-tubes stand around in pans and old cigar boxes. The chemical laboratory is perhaps equal to the teaching of elementary chemistry. The dissecting-room is foul. This description completely exhausts its teaching facilities. There is no museum or library and no teaching accessories of any sort whatsoever.[t]

Shutting down institutions like the Maryland Medical College became Flexner's special mission. After another of his visits, this time to the Medical School of Maine, Flexner concluded that that entire operation was "a disgraceful affair." When Dr. William Thomas Councilman (1854–1933) of Harvard University, who had recently toured the Maine facility and praised it highly, read Flexner's report he predicted that "even Flexner will break down when it comes to Louisville."[u] Faithfully following his Johns Hopkins University standard, Flexner did not break down even with his brother's old alma mater, calling the University of Louisville medical department a school riddled with "radical defects for which there is no end in sight." Assessing the conditions in Kentucky, Flexner stated that "the situation is a simple one. The homeopathic school is without merit. Its graduates deserve no recognition whatsoever, for it lacks the most elementary teaching facilities. The University of Louisville has a large, scattered plant, unequal to the strain which numbers place upon it." On the whole Flexner concluded, "The outlook [for Kentucky] is not promising."[v]

The Flexner Report was not the first or only effort at assessing medical schools in America. As Robert P. Hudson pointed out, the American Medical Association (AMA) "had educational reform as the principal raison d'être from its beginnings in 1848."[w] Despite its desires to fashion medical education in its own image, the AMA made little progress in establishing nationally recognized standards of training for physicians. In 1890, however, the newly reorganized American Medical College Association (AMCA) began to press for change. By 1904 the AMA established a standing Council on Medical Education, a body that began to actively inspect and grade various schools. In 1907 the Council gave its first report, causing the overly optimistic chairman Arthur Dean Bevan to proclaim a great "wave of improvement" in the state of America's medical colleges.[x] These earlier efforts have caused some historians like Howard S. Berliner to conclude that the Flexner Report "has received attention far out of proportion to its actual contribution to medical education and the constant dwelling on the report serves only to mask the real dynamics of the period."[y]

But most historians disagree. Thomas Neville Bonner pointed out that "the history of American medical education would surely have been different without Flexner . . . . Not only did he use philanthropy more imaginatively than any of this contemporaries, he built an enduring model of national policy-making."[z] Unlike the brief and only moderately effectual forays by the AMA and the AMCA against inadequate—even fraudulent—proprietary schools, Flexner's report represented more than a mere raiding party in the attack for substantive educational reform in American medicine. This report had power behind it. With his brother Simon well positioned within the Rockefeller Foundation, Abraham had access to the inner circle of that wealthy and influential organization. In fact it was the association of Abraham Flexner's study with the equally impressive Carnegie Foundation that opened a number of college doors to his whirlwind survey. Many administrators, lured

by the carrot of grant dollars, were more than willing to show Flexner around. "While the Flexner report would undoubtedly have created a stir," insisted John Duffy, "it might well have aroused a brief flurry of attention and then faded away had it not been that Flexner was able to persuade the Rockefeller Foundation to make grants that eventually totaled almost 50 million dollars to those schools that Flexner considered worthwhile. Rockefeller's contributions in turn stimulated other philanthropists to support medical education, with most money going to those institutions designated by Flexner as worthy of support."[aa] Another historian even called the report "the manifesto of a program that by 1936 guided 91 million dollars from Rockefeller's General Education Board (plus millions from other foundations) to a select group of medical schools."[bb]

In attempting to establish medical education on what he considered a sound scientific basis, Flexner was unquestionably influenced by the same forces that helped develop Johns Hopkins into a leader of both medical education and modern graduate training. In the main these new currents in academic education were coming from Europe, especially Germany. Specifically in medicine they stressed clinical training and laboratory research over older didactic classroom methods. In emphasizing this new scientifically based curriculum, it is not inaccurate to consider Flexner an educational elitist more interested in making medicine a rigorous discipline weathered by only a few of the nation's best and brightest than in ensuring that medicine remained a field of egalitarian opportunity open to all. In this sense it is easy to appreciate Robert Hudson's description of this significant report as "Flexner's genteel thunderbolt."[cc]

Flexner's impact was and is unmistakable. While it is true that invigorated state licensing boards and increased economic pressures were closing the more marginal proprietary schools and forcing others to be absorbed into area universities prior to 1910, the report caused closures to accelerate. By 1915, only 96 of Flexner's original 155 medical schools survived; by 1920 the number had fallen to 85; and 10 years later the number stood at 76.[dd] This was still short of Flexner's desired goal of 31, but by 1930 the report had clearly done its intended job.

Looking strictly at the course of events, there is the temptation to see Flexner as the hired gun of a collusion between the foundation behemoths of industrial America and an AMA anxious to strengthen and consolidate its power over the medical profession.[ee] But this conspiracy theory fails on closer examination. Flexner held very specific ideas of what a good medical education should be; the animating spirit of his report was that "all colleges and universities, whether supported by taxation or by private endowment, are in truth public service corporations, and that the public is entitled to know the facts concerning their administration and development . . . ."[ff]

It may come as a surprise to some that Flexner had no special love for the AMA. By the 1920s he was revealing his disdain for the Chicago-based organization in private correspondence to the Rockefeller Foundation's secretary, Edward Embree, calling it the "advertising center in medical education" that "for years tried to make the world think that Chicago was the medical center of this country."[gg] In fact, there is some indication that by 1921 Flexner's enthusiasm for the Johns Hopkins medical school had considerably moderated; astonishingly, he referred to it in at least one letter to Embree as "a rather pitiful institution." These privy communications, however, were never reflected in Flexner's public statements. Years later Flexner saw himself as an integral player in what he and his brother Simon viewed as the "heroic period in American medicine."[hh]

The truth is that the Flexner Report lies somewhere between the extremes of a nefarious plot out to destroy the allopathic (regular) profession's competition and America's official declaration of medical excellence. This report was needed. Certainly by the 20th century the proprietary model had long outlived its usefulness as a method for training America's health care professionals. The increasing financial demands of acquiring and maintaining an expensive laboratory overhead and clinical apparatus forced many marginal institutions out of existence; Flexner's report merely hastened the inevitable, and rightfully so.

Yet Flexner's work was not flawless. There is a nagging sense that he forced, whether in-

tentionally or not, American medical education into an inflexible mold fashioned after the image of the allopathic Johns Hopkins University. When Flexner did come upon a sectarian (irregular) institution worthy of the designation "medical school," he was prone to dismiss it out of hand. For example, he admitted that the Eclectic Medical Institute (EMI) of Cincinnati did justice to its own creed of using botanical medicines but he castigated that creed as "drug mad."[ii] So in the end it was in fact not just the state of the facilities and faculty that mattered (he admitted that the Cincinnati eclectic school had "a new and attractive building, thus far meagerly outfitted"[jj]), but it was also the philosophical underpinnings of the school itself that in some measure determined the verdict. The problem is that Flexner's own allopathic preferences made the mere prospect of financial assistance to a potentially worthy sectarian school virtually out of the question. With the flow of foundation dollars to institutions essentially of Flexner's own choosing, his dismissal of the EMI as the bastion of a "drug mad" minority ensured that the "meagerly outfitted" buildings would indeed remain "meagerly outfitted." His assertion that the eclectics were overly dependent upon their pharmaceutical armamentarium was at its heart a medical and scientific opinion rendered by a layman; Flexner would have been ill-equipped to defend it on clinical grounds. He had overstepped his bounds; he was not by training or background competent to allege that any group of medical practitioners was "drug mad."

Be that as it may, the Flexner Report had another more far reaching flaw: its influence caused medical schools to concentrate in the major metropolitan centers of America, creating an increasing disparity in the quality of health care between rural and urban America. "Flexner insisted in his report that a kind of 'spontaneous dispersion' would spread the graduates of the top medical schools to the four winds. On this matter," wrote Paul Starr, "he was quite wrong. Doctors gravitated strongly to the wealthier areas of the country. A 1920 study by the biostatistician Raymond Pearl showed that the distribution of physicians by region in the United States was closely correlated with per capita income."[kk] The reduced production of physicians encouraged by the Flexner Report certainly aggravated this situation.

In the final analysis the report presents a mixed picture. On the one hand it served to provide a workable national standard upon which modern medical science could build. On the other hand the wholesale closure of sectarian schools reduced the nation's therapeutic choices; the fallout of the report was not beneficial for all Americans, especially those dependent upon country doctors for their primary care. Only recently has the role of alternative and complementary medicine been seriously revisited. The establishment of the Office of Alternative Medicine under the aegis of the National Institutes of Health in 1992 and the work of important researchers like David M. Eisenberg at Beth Israel Deaconess Medical Center in Boston have moved therapies previously deemed unworthy of consideration back within the realm of respectable investigation and discussion.[ll]

Despite the problems created by Flexner's report, these costs were not immediately apparent. Taken in its entirety, health care in America became better for it. "Flexner did not so much instigate reform," wrote John Haller, "as provide a rationale for what should be, as well as what already existed in the form of improved medical instruction and the gradual elimination of marginal schools. His report produced a landmark policy statement that served as a catalyst for medical reform in the years to come."[mm]

Today its historical significance is underscored by the fact that, like most examples of literature that have become classics in their respective fields, it is more often cited than read. This is unfortunate because *Medical Education in the United States and Canada* is a window into the state of American medicine at the beginning of this century unparalleled in its detail and singular influence upon the profession. It represents an unusually frank (if imperfect) assessment of American medicine from an outside observer.

Following the publication of his magnum opus, Flexner remained in the forefront of American education. In 1913 he became secretary of the Rockefeller Foundation's General Education Board, rising in 1925 to the position of board director. In 1930 he expanded his critique of American education

to encompass all of academia in a book titled *Universities—American, English, German.* That same year he established the Institute for Advanced Study at Princeton University, a project he directed until his retirement in 1939.

When Abraham Flexner died on 21 September 1959 at Falls Church, Virginia, American medicine lamented the loss of the last of two remarkable brothers who gave their all in pursuit of better medicine. The Flexners left an indelible mark on the medical profession. Kentucky can be proud that their formative years were spent in Louisville and that this city on the Ohio River provided them with the initial opportunities that would ultimately make them both famous.

Michael A. Flannery
Lloyd Library and Museum
917 Plum Street
Cincinnati, OH 45202

ENDNOTES

a. Biographical information on Simon Flexner is available in George W. Corner, s.v. "Flexner, Simon," *Dictionary of Scientific Biography,* ed. Charles Coulston Gillispie (New York, Charles Scribner's Sons, 1972); and S. Bayne-Jones, s.v. "Flexner, Simon," *The American Philosophical Society Year Book, 1946* (Philadelphia: The Society, 1947). Additional autobiographical material is presented in Simon and James Thomas Flexner's *William Henry Welch and the Heroic Age of American Medicine* (1941; Johns Hopkins University Press, 1993).

b. Qtd. in Flexner, *William Henry Welch,* p. 160.

c. Flexner, *William Henry Welch,* p. 165.

d. Richard B. Morris, ed., *Encyclopedia of American History* (New York: Harper & Row, 1976), p. 345.

e. Flexner, *William Henry Welch,* p. 246.

f. Shiga's discovery occurred in 1897. Flexner's date of 1898 must refer to Shiga's published results, not his actual discovery. See Kiyoshi Shiga, *Sekiri byogen kenkyu hokoku* [Report on the bacterial studies relating to the origin of dysenteries] (Tokyo: Densenbyo Kenkyusho, 1898). For Flexner's work on dysentery see his "On the Etiology of Tropical Dysentery," Johns Hopkins Hosp. Bull. 11 (1900):231–242.

g. For Flexner and Noguchi's work on snake venom see their "Snake venom in relation to haemolysis, bacteriolysis, and toxicity," J. Exp. Med. 2 (1909): 277–301. Biographical information is available on Noguchi in Claude E. Dolman, s.v. "Noguchi, Hideyo," *Dictionary of Scientific Biography.*

h. Qtd. in Flexner, *William Henry Welch,* p. 280.

i. Qtd. in Flexner, *William Henry Welch,* p. 280.

j. Bayne-Jones, *American Philosophical Society,* p. 293.

k. This new class of antibacterial agents was heralded in by the German chemist-pharmacologist Gerhard Domagk (1895–1964) in 1935 when he discovered the specific compound responsible for Prontosil's antibacterial action against streptococcal infections. See *Kremers and Urdang's History of Pharmacy,* rev. ed. Glenn Sonnedecker (Phildelphia: Lippincott, 1976), pp. 50–56; and Eric Posner, s.v. "Domagk, Gerhard," *Dictionary of Scientific Biography.* For Flexner's cerebrospinal meningitis antiserum see his article "Concerning a Serum Therapy for Experimental Infection with Diplococcus intracelluraris," J. Exp. Med. 9 (1907):168–185; and Simon Flexner and James Wesley Jobling, "Serum Treatment of Epidemic Cerebro-spinal Meningitis," J. Exp. Med. 10 (1908):141–203.

l. Bayne-Jones, *American Philosophical Society,* p. 295. See also Simon Flexner and Paul A. Lewis, "Experimental poliomyelitis in monkeys: active immunization and passive serum protection," JAMA 54 (1910): 1780–1782.

m. S. Bayne-Jones, *American Philosophical Society,* p. 296.

n. David Banta, "Abraham Flexner—A reappraisal," Soc. Sci. & Med. 6 (1971):655–661.

o. Abraham Flexner, *Abraham Flexner: An Autobiography* (New York: Simon & Schuster, 1960), pp. 74–75. Originally published in 1940 as *I Remember: An Autobiography.*

p. Abraham Flexner, *Medical Education in the United States and Canada: A report to the Carnegie Foundation for the Advancement of Teaching,* Bulletin 4 (New York: Carnegie Foundation, 1910), p. 151.

q. Flexner, *Medical Education,* pp. 18–19.

r. John Duffy, *From Humors to Medical Science: A History of American Medicine,* 2nd ed. (Urbana: University of Illinois Press, 1993), pp. 133–134.

s. Flexner, *Medical Education,* p. xii.

t. Flexner, *Medical Education,* p. 237.

u. Flexner, *Abraham Flexner: An Autobiography,* p. 81.

v. Flexner, *Medical Education,* pp. 230–231.

w. Robert P. Hudson, "Abraham Flexner in Historical Perspective," in *Beyond Flexner: Medical Education in the Twentieth Century,* Barbara Barzansky and Norman Gevitz, eds. (New York: Greenwood Press, 1992), p. 6.

x. Qtd. in Howard S. Berliner, "New Light on the Flexner Report: Notes on the AMA-Carnegie Foundation Background," *Bull. Hist. Med.* 51 (Winter 1977): 604.

y. Berliner, "New Light on the Flexner Report," p. 608.

z. Thomas Neville Bonner, "Abraham Flexner and the Historians," J. Hist. Med. & Allied Sci. 45 (1990):7.

aa. Duffy, *From Humors to Medical Science,* p. 209.

bb. Paul Starr, *The Social Transformation of American Medicine* (New York: Basic Books, 1982), p. 121.

cc. Robert P. Hudson, "Abraham Flexner in Perspective:

American Medical Education, 1865–1910," Bull. Hist. Med. 46 (November/December 1972): 545.

dd. Hudson, "Abraham Flexner in Historical Perspective," p. 8.

ee. This has been suggested more than once, not only by proponents of alternative medicine but also by some revisionist historians. See, for example, Paul Bergner, foreword to *Official Herbs: Botanical Substances in the United States Pharmacopoeias, 1820–1990,* by Wade Boyle (East Palestine, OH: Buckeye Naturopathic Press, 1991), p. xv; George Cody, "History of Naturopathic Medicine," in *A Textbook of Natural Medicine,* Joseph E. Pizzorno Jr. and Michael T. Murray, eds. (Seattle: Bastyr University Press, 1993), pp. 6–7; and Gerald Markowitz and David Rosner, "Doctors in Crisis: A Study of the Use of Medical Education Reform to Establish Modern Professional Elitism in Medicine," Am. Q. 25 (1973):83–90.

ff. Flexner, *Medical Education,* p. ix.

gg. Qtd. in Daniel M. Fox, "Abraham Flexner's Unpublished Report: Foundations and Medical Education, 1909–1928," Bull. Hist. Med. 54 (Winter 1980):493.

hh. Qtd. in Fox, "Flexner's Unpublished Report," 495.

ii. Flexner, *Medical Education,* p. 163.

jj. Flexner, *Medical Education,* p. 162.

kk. Starr, *The Social Transformation of American Medicine,* p. 125.

ll. See David M. Eisenberg, "Unconventional Medicine in the United States," New Engl. J. Med. 328 (Jan. 28, 1993):246–252; and David M. Eisenberg, "Advising Patients Who Seek Alternative Medical Therapies," Ann. Int. Med. 127 (July 1, 1997):61–69.

mm. John S. Haller Jr., *American Medicine in Transition, 1840–1910* (Urbana: University of Illinois Press, 1981), p. 229.

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Winter-bird Communities in a Western Mesophytic Forest and Two Proximate Urban Habitats

David L. Hedeen

Department of Entomology and Applied Ecology, University of Delaware, Newark, Delaware 19717

and

Stanley E. Hedeen

Department of Biology, Xavier University, Cincinnati, Ohio 45207

ABSTRACT

Winter-bird communities in Cincinnati, Ohio, were compared along 500 m transects in three habitats: a Western Mesophytic Forest remnant, a residential area with lawns holding scattered shrubs and trees, and a railroad corridor with a railway track bordered on each side by strips of herbaceous vegetation, seral woodland, and backyard lawns. Bird surveys were conducted between 9 Nov and 3 Feb for four winters, 1990–1994. Compared to the forest, the residential area held fewer bark-feeding individuals and more ground-feeding birds, most of which were non-natives. The high populations of non-natives caused the residential area to have a larger abundance of birds than the forest but also a lower Simpson index of species diversity. Species richness totaled 31 in the forest, 34 in the residential area, and 41 in the railroad corridor. Of the three habitats, the railroad corridor supported the greatest abundance of birds, probably due to its greater variety and amount of food-producing vegetation.

INTRODUCTION

The Western Mesophytic Forest Region, covering the western two-thirds of Kentucky and Tennessee, extends from northern Mississippi and Alabama north to southern Illinois, Indiana, and Ohio (Braun 1950). Changes in land use have vastly influenced the region's biotic community. For example, the avifauna of the Cincinnati metropolitan area in northern Kentucky and southwestern Ohio has been altered by deforestation and urbanization (Kemsies 1948; Trautman 1977). Beissinger and Osborne (1982) documented that the summer-bird community of a residential district near Cincinnati is significantly different from that of a local climax forest.

Urbanization also might change the structure of the region's winter-bird communities. Although there have not been previous studies of such alterations in any deciduous forest region, winter avian populations in natural and urban habitats have been compared in a coastal sage-scrub zone in California (Guthrie 1974), a coniferous forest area of Washington (Gavareski 1976), and a southeastern pine region in Georgia (Yaukey 1996). Our objective in this study in Cincinnati, Ohio, was to contrast the winter-bird community of a Western Mesophytic Forest remnant with such communities in a city residential area and an urban railroad corridor.

MATERIALS AND METHODS

Our study was conducted in the southeast quarter of Section 21, Fractional Range 2, Township 4, City of Cincinnati, Hamilton County, Ohio. At the time of Cincinnati's settlement, this 65-ha area was covered by deciduous forest (Gordon 1966). A 15-ha old-growth forest remains within the city park that occupies the southern portion of the study area. Braun (1950) gave a detailed account of this Ault Park woodland as a typical example of a Western Mesophytic Forest stand. The structure and tree species composition of this climax forest show little evidence of past human or natural disturbance (Bryant 1987).

The northern portion of the study area was cleared and developed as a residential area. Most of the residences are detached single-family homes built during the 1920s. Original forest vegetation was replaced by lawns with scattered shrubs and trees.

The residential area is bisected by a 30-m wide east-west railroad right-of-way cleared in the 1880s. The infrequently used train route ends in a nearby industrial area. Chemical

sprays and flail mowers maintain a ca. 10-m wide herbaceous community centered on the train track at the middle of the right-of-way. Secondary succession has reestablished shrubs and trees along the ca. 10-m wide margins of the right-of-way. The backyard lawns bordering the outside edges of the right-of-way complete the railroad corridor.

We established a 500-m census transect in the climax woodland. The small size of the forest remnant precluded the establishment of more than one transect in the stand. Two other 500-m transects were established: one along a city street in the residential area and one along the train track in the railroad corridor.

Between 1100 and 1500 on a count day, we walked together at a speed of 1 km/hr to census a transect in 30 min. This pace allowed all three transects to be censused within a 2-hr period. Except for gulls and waterfowl flying over the transects, all birds seen or heard were counted. Due to the winter absence of leaves, lines of sight and sound were equivalent along all three transects. The recorded species were assigned to one of 10 winter foraging guild categories defined by DeGraaf et al. (1985). A foraging guild is composed of species with similar habitat-use patterns as defined by primary food, feeding substrate, and feeding behavior.

Because patterns of diversity and abundance may vary within a season (Kricher 1975), 10 counts were made over the course of a winter, with an average span of 10 days between counts. Because winter-bird populations and communities also may vary from year to year due to numerous factors (Block and Brennan 1993; Smith 1984; Weins 1989), counts were conducted over four consecutive winters from 1990–1991 through 1993–1994. The census dates varied from one winter to the next, but all counts were completed between 9 Nov and 3 Feb to minimize the effects of food shortages later in the winter that may cause movement to feeders (Rollfinke and Yahner 1990).

Species diversity for each transect was calculated by using Simpson's index of diversity (Brower et al. 1990; Simpson 1949). This index incorporates the number of species (index of species richness) and the equitability of bird numbers among the species (index of species evenness).

RESULTS

The 10 feeding guilds were not equally represented in all three habitats (Table 1). The forest, for example, supported more insectivorous bark gleaners and fewer seed-eating ground foragers. Overall, the greatest number of bark feeders and the least number of ground feeders were recorded in the forest (Figure 1).

Compared to the forest, the residential area held about twice as many individual birds, while the railroad corridor supported about three times as many. The larger bird populations in the urbanized habitats were largely due to increased numbers of exotic birds. Non-native rock doves, European starlings, house finches, and house sparrows together averaged 65.6 birds in the residential area, 65.9 birds in the railroad corridor, and 5.9 birds in the forest. Of the total individuals in each habitat, the proportion of non-natives was 68% in the residential area, 48% in the railroad corridor, and 12% in the forest.

The forest had the least species richness and the most evenness of bird numbers among its species (Table 2). The forest's species diversity index was significantly greater than that of the residential area ($t_\infty = 2.08$, $P < 0.05$), but was not significantly different from the index of the railroad corridor ($t_\infty = 0.62$, NS).

DISCUSSION

The site of Cincinnati was entirely covered by deciduous forest when it was initially surveyed in 1788 (Gordon 1966; Symmes 1926). Two centuries later, urban development has reduced the old-growth forest to a few remnants such as the stand in Ault Park (Bryant 1987). In contrast to the climax woodland, trees in Cincinnati's residential neighborhoods are widely dispersed, existing only where they provide shade, privacy, landscape scenery, or some other benefit to the human residents.

In our study, the sparsely wooded residential area supported fewer bark-feeding birds than did the adjacent climax forest (Figure 1). Species associated with woody plants typically decrease in abundance as forested areas undergo housing development (Beissinger and Osborne 1982; DeGraaf and Wentworth 1981; Lancaster and Rees 1979). This downward trend is the opposite of what occurs during

Table 1. Foraging guilds and mean number of each species detected along a 500 m transect in each of three winter habitats in Cincinnati, Ohio, 9 Nov–3 Feb, 1990–1994.

Species	Climax forest	Residential area	Railroad corridor
Insectivorous Bark Excavator			
Pileated woodpecker (*Dryocopus pileatus*)	0.48	0.03	0.08
Insectivorous Bark Gleaners			
Red-bellied woodpecker (*Melanerpes carolinus*)	2.43	0.38	0.95
Yellow-bellied sapsucker (*Sphyrapicus varius*)	0.45	0.10	0.13
Downy woodpecker (*Picoides pubescens*)	2.15	0.55	1.40
Hairy woodpecker (*Picoides villosus*)	0.90	0.05	0.18
Red-breasted nuthatch (*Sitta canadensis*)	—	0.03	—
White-breasted nuthatch (*Sitta carolinensis*)	1.35	0.15	0.50
Brown creeper (*Certhia americana*)	1.23	0.03	0.25
Omnivorous Crown Foragers			
Northern flicker (*Colaptes auratus*)	0.10	0.03	0.18
Carolina chickadee (*Parus carolinensis*)	8.08	4.35	7.23
Tufted titmouse (*Parus bicolor*)	2.40	0.83	1.58
Insectivorous Crown Gleaners			
Carolina wren (*Thryothorus ludovicianus*)	2.30	0.33	2.30
Golden-crowned kinglet (*Regulus satrapa*)	0.48	0.18	0.20
Ruby-crowned kinglet (*Regulus calendula*)	0.05	—	0.03
Blackpoll warbler (*Dendroica striata*)	—	—	0.03
Frugivorous Crown Foragers			
Northern mockingbird (*Mimus polyglottos*)	—	1.25	1.28
Cedar waxwing (*Bombycilla cedrorum*)	0.90	0.33	0.98
Seed-eating Crown Gleaner			
Pine siskin (*Carduelis pinus*)	—	1.73	0.30
Omnivorous Ground Foragers			
Rock dove (*Columba livia*)	1.05	1.80	4.75
Blue jay (*Cyanocitta cristata*)	0.58	0.50	1.03
American crow (*Corvus brachyrhynchos*)	4.63	2.63	4.65
Swainson's thrush (*Catharus ustulatus*)	0.03	—	—
Hermit thrush (*Catharus guttatus*)	—	0.03	—
American robin (*Turdus migratorius*)	7.38	5.50	10.58
European starling (*Sturnus vulgaris*)	3.15	33.20	32.33
Rufous-sided towhee (*Pipilo erythrophthalmus*)	0.03	—	0.15
Common grackle (*Quiscalus quiscula*)	0.03	0.10	0.03
Insectivorous Ground Gleaner			
Winter wren (*Troglodytes troglodytes*)	—	—	0.03
Carnivorous Ground Hawkers			
Sharp-shinned hawk (*Accipiter striatus*)	0.03	—	0.13
Cooper's hawk (*Accipiter cooperii*)	—	0.05	0.05
Red-tailed hawk (*Buteo jamaicensis*)	0.20	0.03	0.23
American kestrel (*Falco sparverius*)	—	—	0.03
Barred owl (*Strix varia*)	—	—	0.03
Seed-eating Ground Foragers			
Mourning dove (*Zenaida macroura*)	—	2.05	5.75
Northern cardinal (*Cardinalis cardinalis*)	2.20	2.08	13.78
Fox sparrow (*Passerella iliaca*)	—	—	0.03
Song sparrow (*Melospiza melodia*)	0.08	0.15	1.83
White-throated sparrow (*Zonotrichia albicollis*)	0.40	—	6.48
Dark-eyed junco (*Junco hyemalis*)	0.50	1.38	4.63
Red-winged blackbird (*Agelaius phoeniceus*)	—	0.63	0.03
Brown-headed cowbird (*Molothrus ater*)	0.03	2.98	1.60
House finch (*Carpodacus mexicanus*)	1.65	6.90	18.63
American goldfinch (*Carduelis tristis*)	1.95	2.60	3.63
House sparrow (*Passer domesticus*)	—	23.73	10.23
Total	47.22	96.69	138.24

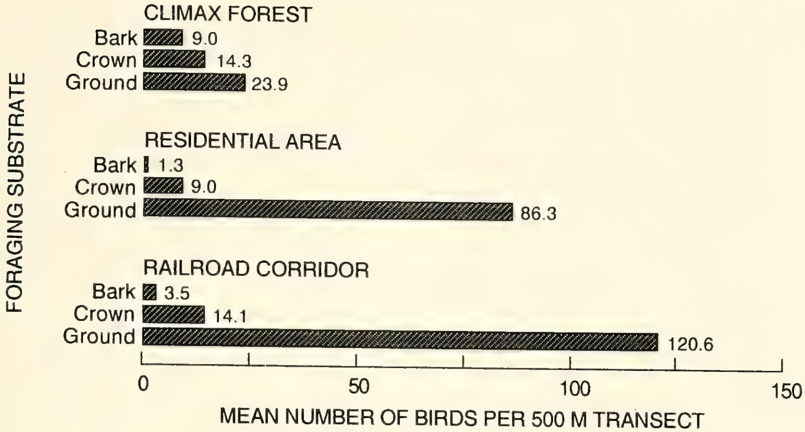

Figure 1. Bird abundance by foraging substrate in three winter habitats in Cincinnati, Ohio, 9 Nov—3 Feb, 1990–1994.

residential development in deserts, grasslands, and shrublands, where the propagation of artificially watered woody vegetation increases the arboreal avifauna (Emlen 1974; Guthrie 1974).

The winter abundance of ground-feeding birds is positively associated with the density of non-woody vegetation (Tilghman 1987). In more open tree stands, the fuller development of the herbaceous layer provides more seeds that persist in winter for ground foragers. The association of open terrain with ground-feeding species was evident in our study where the proportion of birds that were ground feeders rose from 51% in the Ault Park forest to 89% in the lawn-dominated residential area (Figure 1). DeGraaf (1991) reported similar figures from Amherst, Massachusetts, where the proportions of winter ground feeders were 45% in a suburban woodland and 92% in a suburb with large lawns and few shrubs or trees.

Summarizing several breeding and non-breeding season studies on avifaunal change caused by urbanization, Cicero (1989) concluded that natural habitats have higher species richness than do nearby urban neighborhoods. However, in a study of the winter avifauna of neighborhoods in Amherst, Massachusetts, DeGraaf (1991) found that the number of species was smaller in a wooded zone (24 species) than in either of two residential areas with lower tree densities (26 species each). The slightly lower avian species richness in natural woodland also was the pattern found in our study (Table 2), perhaps reflecting a less heterogeneous flora in the closed Ault Park forest than in the landscaped yards of the residential area.

Table 2. Bird community indices in three winter habitats in Cincinnati, Ohio, 9 Nov–3 Feb, 1990–1994.

Index	Climax forest	Residential area	Railroad corridor
Species diversity	11.65	5.18	9.43
Species evenness	0.37	0.15	0.23
Species richness	31	34	41

Although the residential area had a slightly greater species richness than the climax forest, it nonetheless had a significantly smaller index of species diversity due to its much lower species evenness. Species evenness typically declines in urban areas because the extensive habitat modification associated with urbanization allows the proliferation of exotic species (Cicero 1989; Williamson and DeGraaf 1980). In our study (Table 1), the non-native European starlings, house sparrows, house finches, and rock doves represented 12% of the residential area's total species and 68% of its total individuals. In contrast, exotics constituted 10% of the forest's species and 12% of the forest's individuals.

The European starling alone composed one-third of the total of the birds in the residential area. The residential area's lawns provided the species with large expanses of grass, the starling's preferred foraging habitat (Feare 1984). A quarter of the birds in the residential area were house sparrows, a species not found

in the Ault Park forest. The absence of house sparrows from woodlands also has been recorded in Columbia, Maryland, and Vancouver, British Columbia, although they are abundant in the residential areas of these cities (Geis 1974; Lancaster and Rees 1979). Throughout the world, the house sparrow has an affinity for developed areas (Summers-Smith 1963).

The introduced rock dove and house finch also had populations that were higher in the residential area than in the forest. These two birds are like the European starling and house sparrow in that they are ground-foraging omnivorous and seed-eating species that are everywhere associated with the built environment (Gilbert 1989; Guthrie 1974; Williamson 1974). Goldstein-Golding (1991), summarizing several studies on the effect of urbanization on birds, concluded that the dramatic population increases of exotic species cause urban areas to have a greater density of individuals than do nearby natural areas. In our study, the abundance of non-native individuals in the residential area resulted in a total bird count that was double the total found in the forest.

In comparison to the forest and residential area, the railroad corridor supported the greatest bird abundance and species richness, reflecting its vegetation structure. The herbaceous plant community along the train track at the center of the right-of-way is bordered on each side by a seral woodland community. Beyond the wooded margins of the right-of-way are located the lawns of adjacent backyards. Due to increased light penetration through the open spaces above the train track and the fringing lawns, the shrub and herbaceous layers are more fully developed below the trees in the right-of-way than they are in the closed climax forest or in the mowed and manicured residential area.

The increased volume and diversity of foliage probably were responsible for the greater avian abundance and larger number of species occurring in the railroad corridor. In North American deciduous forests, increased growth in the fruit- and seed-producing shrub and herbaceous layers during the growing season leads to a greater density and variety of winter bird life (McComb and Moriarity 1981; Quay 1947; Tilghman 1987). Elevated avian abundance and higher bird species richness also have been noted in the heterogeneous vegetation of railroad corridors in Britain (Gilbert 1989).

Our study's findings must be considered as preliminary, as it only was possible to establish single transects in each of the three locally restricted habitat types. However, the results suggest that urbanization alters the size and composition of the winter-bird community in a deciduous forest region.

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Observations of Forest-interior Bird Communities in Older-growth Forests in Eastern Kentucky

Michael J. Lacki and Michael D. Baker

Department of Forestry, University of Kentucky, Lexington, Kentucky 40546

ABSTRACT

Quantitative data on the composition of forest-interior bird communities in older-growth forests of eastern Kentucky are needed to assess the status of potential source populations of birds for an increasingly fragmented-forest landscape. We surveyed forest-interior bird communities in Robinson Forest, Breathitt County, and Lilley Cornett Woods, Letcher County, Kentucky, in May and June 1994 and 1995. Red-eyed vireo (*Vireo olivaceus*), ovenbird (*Seiurus aurocapillus*), black-throated green warbler (*Dendroica virens*), and acadian flycatcher (*Empidonax virescens*) in that order were the four species most frequently recorded. Two additional species, solitary vireo (*V. solitarius*) and common raven (*Corvus corax*), were observed in Breathitt County, where breeding populations of these species have not been reported. Although only a single brown-headed cowbird (*Molothrus ater*) was noted in surveys, it does indicate that this species enters intact blocks of forest in eastern Kentucky; a need exists for information on nest success and parasitism levels by brown-headed cowbirds in such forests in eastern Kentucky.

INTRODUCTION

Conservation of habitat for forest-interior birds has focused on identification and protection of intact blocks of older-growth forest (i.e., core areas with mature timber +70 years in age; Hagan 1995) to provide for source populations of forest-interior birds occurring in heavily fragmented landscapes (Donovan et al. 1995; Hagan et al. 1996; Robinson et al. 1995). Fragmentation of forests has reduced nesting success of forest-interior birds through habitat loss (Hagan et al. 1996; Robbins et al. 1989; Temple and Cary 1988), increased nest predation (Gates and Gysel 1978; Wilcove 1985; Yahner and Scott 1988), increased parasitism by brown-headed cowbirds (Brittingham and Temple 1983; Hoover and Brittingham 1993; Robinson et al. 1995), and disruption of pairing success and habitat selection (Porneluzi et al. 1993; Van Horne et al. 1995; Villard et al. 1993). The required size of forest blocks and the landscape context necessary for fragments of forest to support source populations of forest-interior birds remains largely unresolved (Brawn and Robinson 1996; Donovan et al. 1995). Because requirements are likely to vary among physiographic regions (Robinson et al. 1995), information on status of breeding-bird communities and forest conditions is needed from interior forests representing a variety of forest types and physiographic locations.

Eastern Kentucky is a predominantly forested landscape comprised of rich mesophytic forest, giving way to mixed pine-hardwoods at southerly latitudes and on ridges (Braun 1950; Palmer-Ball 1996). Because of its extensive forests, eastern Kentucky may be a conservation area for forest-interior birds inhabiting these forest ecosystems. Logging, surface mining, and clearing of land for agriculture and settlement continue to alter forests in eastern Kentucky, and many locations now support second-growth forest or early successional vegetation (Palmer-Ball 1996). Historical patterns of land use in eastern Kentucky suggest that fragmentation of forests can be expected to continue; thus, identification and protection of forest blocks containing older-growth forest and associated bird communities are necessary to ensure the long-term conservation of forest-interior birds in this region. We present data on forest-interior bird communities from two older-growth forests in eastern Kentucky, with an emphasis on species composition and the occurrence of the brown-headed cowbird.

STUDY AREA

Robinson Forest, which covers ca. 5,000 ha in Breathitt, Knott, and Perry counties, Kentucky, is owned in trust by the University of Kentucky. This tract is an island of second-growth forest surrounded by both active and reclaimed surface coal mines. Logging ceased on the forest in 1923; stands chosen for our surveys have been undisturbed since 1915 and were ca. 79 years in age at the start of surveys.

Lilley Cornett Woods is a 104-ha tract of virgin timber situated in Letcher County, Kentucky, with protected status as a Kentucky state forest (Martin 1975). This tract is surrounded by a combination of secondary forest, small areas of cultivated land, and surface coal mining operations. Both forests have steep slopes and narrow ridges and valleys, have elevations ranging from 244 to 588 m, and support a mixed mesophytic vegetation complex (Braun 1950). Vegetation is characterized by American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), yellow-poplar (*Liriodendron tulipifera*), eastern hemlock (*Tsuga canadensis*), white oak (*Quercus alba*), northern red oak (*Q. rubra*), cucumber tree (*Magnolia acuminata*), basswood (*Tilia* spp.), and upland hickories (*Carya* spp.) in the overstory. Understories are comprised of flowering dogwood (*Cornus florida*), spicebush (*Lindera benzoin*), sassafras (*Sassafras albidum*), hawthorns (*Crataegus* spp.), eastern hophornbeam (*Ostrya virginiana*), American hornbeam (*Carpinus caroliniana*), redbud (*Cercis canadensis*), serviceberry (*Amelanchier* sp.), and rhododendron (*Rhododendron* spp.). At least 69 species of woody plants are known to occur in Lilley Cornett Woods (Martin and Shepherd 1973).

METHODS

Birds were surveyed in Robinson Forest on 17 May and 14 June 1994 and on 13 May and 10 June 1995. Surveys in Lilley Cornett Woods were conducted on 18 May and 15 June 1994 and on 12 May and 9 June 1995. Four representative stands (i.e., no history of fire or recent disturbance) were selected for sampling in each forest. Each stand was surveyed at one point in both May and June during both years of the survey. A modified, fixed-radius point-count method (Hutto et al. 1986) was used to survey birds, primarily of singing males, with data partitioned into <50 m and >50 m concentric distance bands. All survey points were >200 m apart and >150 m from any forest edge. All birds seen or heard during surveys were recorded. Surveys were conducted between 0630 and 0930 EDST. Survey periods were 12 minutes long. We waited 3 minutes from the time of arrival at the survey point before collecting data to permit disturbed birds to resume normal singing activity. Surveys took place only when the weather was favorable.

Data provided an estimate of the relative abundance of species and were organized into two community indices: abundance (number of individual birds/point) and richness (number of species/point). Forests were compared using community indices derived from data for the <50-m distance bands. Comparisons were based on Student's *t*-tests, with differences considered significant at $p<0.05$.

RESULTS AND DISCUSSION

A total of 44 species of birds was recorded, 36 in Robinson Forest and 34 in Lilley Cornett Woods (Table 1). In general, avifaunal composition was comparable with 26 species found at both forests. Notable differences were the presence of a common raven (*Corvus corax*) and a solitary vireo (*Vireo solitarius*) in Robinson Forest. The raven was heard flying over Deadman's Hollow on 10 June 1995 shortly after 0630. Historically, this species was a resident on the Cumberland Plateau but was presumed extirpated from the region by the 1950s (Mengel 1965). A recent observation in Leslie County, Kentucky (Palmer-Ball 1996), and the location of a nest site in Letcher County, Kentucky (Fowler et al. 1985), suggest that common ravens are increasing in frequency in this state. Our observation, the first modern record from Breathitt County, suggests that this species is beginning to extend its range to the northwest. The common raven is presently listed as endangered in Kentucky (KSNPC 1996). The solitary vireo is believed to be a summer resident only at higher elevations in Kentucky and is not documented in summer from Breathitt County (Palmer-Ball 1996); however, this species was recently discovered at many sites across the Cumberland Plateau and also appears to be extending its summer range (Palmer-Ball 1996).

The community indices of birds in these forests were similar. Abundance at Robinson Forest (x = 14.6 (SE = 0.72)) and Lilley Cornett Woods (x = 13.7 (SE = 0.94)) was not different (t= 0.79, P = 0.44), and species richness at Robinson Forest (x = 8.81 (SE = 0.53)) and Lilley Cornett Woods (x = 9.44 (SE = 0.61)) was not different (t = 0.77, P = 0.44). For the combined data set, the most

Table 1. Species and numbers of birds, in order of abundance, recorded by distance from sampling points in two older-growth forests in eastern Kentucky, 1994 and 1995. Data are based on 16 surveys per site.

Species	Robinson Forest		Lilley Cornett Woods	
	<50 m	>50 m	<50 m	>50 m
Vireo olivaceus	51	11	39	8
Seiurus aurocapillus	40	10	29	9
Dendroica virens	16	2	25	3
Empidonax virescens	28		15	
Corvus brachyrhynchos	6	22		13
Hylocichla mustelina	4	9	9	10
Dryocopus pileatus	8	7	9	5
Parus bicolor	7	11	4	5
Parula americana	14		6	1
Piranga olivacea	3	2	11	5
Wilsonia citrina	6		10	2
Sitta carolinensis	4	3	5	4
Colaptes auratus	3	4	4	2
Melanerpes carolinus	1		6	2
Vireo flavifrons	5		4	
Mniotilta varia	4	2	3	
Polioptila caerulea	5		3	
Dendroica cerulea	2		4	2
Dendroica magnolia[1]	6		2	
Cardinalis cardinalis	2		1	5
Contopus virens		1	5	1
Catharus ustulatus[1]	2		5	
Helmitheros vermivorus	3	1	2	
Coccyzus americanus			3	1
Parus carolinensis	1	1	2	
Dendroica dominica	4			
Setophaga ruticilla			4	
Dendroica pinus			3	
Zenaida macroura	2			
Strix varia		1		1
Picoides pubescens	2			
Picoides villosus	1		1	
Cyanocitta cristata			1	1
Oporornis formosus			1	1
Piranga rubra	1	1		
Buteo lineatus		1		
Meleagris gallopavo			1	
Sayornis phoebe			1	
Corvus corax		1		
Sialia sialis		1		
Dumetella carolinensis	1			
Vireo solitarius	1			
Seiurus motacilla	1			
Molothrus ater			1	

[1] Probable migrant (Palmer-Ball 1996).

frequently recorded species were red-eyed vireo (*Vireo olivaceus*), ovenbird (*Seiurus aurocapillus*), black-throated green warbler (*Dendroica virens*), and acadian flycatcher (*Empidonax virescens*) in that order (Table 1), with red-eyed vireos and ovenbirds being the most numerous in each forest. Data on relative abundance of red-eyed vireos and ovenbirds were consistent with historical (Mengel 1965) and recent trends (Palmer-Ball 1996) for these two species in eastern Kentucky.

The American crow (*Corvus brachyrhynchos*) was third and the black-throated green warbler and tufted titmouse (*Parus bicolor*) were fourth in relative abundance at Robinson Forest; most of the crows were recorded at >50 m from sample points. At Lilley Cornett Woods, the black-throated green warbler and the wood thrush (*Hylocichla mustelina*) were third and fourth in relative abundance. Wetmore (1940) suggested that black-throated green warblers were locally common in Letcher County, Kentucky; however, surveys at Lilley Cornett Woods in the 1970s (Hudson 1971, 1972) produced only four records of black-throated green warblers. Further, surveys in 1955 along Clemon's Fork in Robinson Forest (Barbour 1956) produced few of the warblers. Palmer-Ball (1996) suggested that this species has only slightly decreased in abundance in eastern Kentucky. The abundance of the black-throated green warbler in our surveys, and in recent surveys in oak-hickory forest further north in Bath County, Kentucky (Baker and Lacki 1997), indicates that this species is locally common in older-growth forests in eastern Kentucky.

We heard one male brown-headed cowbird in the 32 surveys: on 15 June 1994 in Lilley Cornett Woods within 50 m of the sampling point. This observation indicates that the brown-headed cowbird does enter interior portions of smaller forest blocks in eastern Kentucky. Hahn and Hatfield (1995) documented nest parasitism by cowbirds in a 1,300-ha forest block in New York and suggested that regional differences exist in habitat use and selection of hosts by cowbirds. Given that cowbirds are known to make use of reclaimed strip mines in spring and summer in eastern Kentucky (Claus et al. 1988) and that strip mining continues to be a major source of habitat fragmentation in this region, increased pressures on host species in nearby forest fragments are likely. Claus et al. (1988) postulated that many cowbirds inhabiting reclaimed strip mines are unpaired, non-breeding birds; however, no data exist to support or refute this hypothesis.

The two species recorded most frequently in our study, red-eyed vireo and ovenbird, are

positively correlated with the size of forested area around survey points in the middle Atlantic states (Robbins et al. 1989). Further, rates of nest parasitism of these two species by cowbirds are also associated with the frequency of detection of cowbirds in Missouri, Minnesota, and Wisconsin, including both contiguous and fragmented forests (Donovan et al. 1995). We recommend studies to assess the extent that the the cowbird affects nest success of forest-interior birds in eastern Kentucky, particularly stands in close proximity to reclaimed strip mines.

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Characterization of the Woody Strata in the Xeric-site Chestnut Oak Forest Community, Northwestern Highland Rim, Kentucky and Tennessee

Edward W. Chester, Christine E. Harris, and Sandra Gonzalez

Department of Biology, Austin Peay State University, Clarksville, Tennessee 37044

and

Keri K. Denley

Department of Biology, Delta State University, Cleveland, Mississippi 38733

ABSTRACT

Forests dominated by xerophytic oaks, especially chestnut (mountain) oak (*Quercus prinus* = *Q. montana*), occupy many rocky-gravelly, nutrient-poor ridges and upper slopes between the Cumberland and Tennessee rivers in southwest-central Kentucky (Lyon and Trigg counties)and northwest-central Tennessee (Stewart County). Those xeric-site remnants that are least disturbed may represent some of the best remaining examples of pre-settlement forests of the region. We here characterize the woody strata of 10 such forest stands in the three-county area of Land Between The Lakes. Stands were specifically and non-randomly selected based on topography and xeric conditions, the presence of numerous and mature chestnut oaks in the canopy, and lack of recent disturbance. Based on data from 45 0.04-ha plots, all strata are dominated by *Q. prinus*, and mesophytic species such as sugar maple are mostly lacking in the understory, suggesting stability in these remnants.

INTRODUCTION

The eastern deciduous biome is dominated by temperate hardwood forest types except for peripheral areas (Abrams 1996; Braun 1950). In the hardwood-dominated forests, oaks (*Quercus*) are most often encountered (Abrams 1996; Monk et al. 1990). *Quercus prinus* (*Q. montana*), chestnut or mountain oak, the subject species in this study, ranges over much of the biome north and west of the Coastal Plain (Nixon and Muller 1997) and is one of six oak species of particular significance because of high dominance in eastern North America (Abrams 1996). It is a major component of two Society of American Foresters cover types (Eyre 1980) and an important member of several of the forest regions of Braun (1950). The considerable significance of *Q. prinus* in Kentucky and Tennessee forests was discussed in Baskin et al. (1987) for Kentucky, in Chester (1989) for Tennessee, and in the forest region summaries for southeastern United States in Martin et al. (1993).

In Land Between The Lakes (LBL), the 68,000-ha peninsula between the lower Cumberland and Tennessee rivers, many xeric ridges and upper slopes are dominated by chestnut oak. Franklin and Fralish (1994), based on research by Fralish et al. (1991) in southern Illinois, suggested that such xeric-site oak stands may best represent pre-European settlement conditions in the region. We have collected considerable data on the composition and characteristics of successional and mature chestnut oak forests in LBL. The purpose of our paper is to present analyses of the woody strata in 10 non-randomly selected mature stands.

The Study Area

Land Between The Lakes is within and at the western edge of the Western Highland Rim Subsection, Highland Rim Section, Interior Low Plateaus Province (Quarterman and Powell 1978). The landscape is heavily dissected with narrow ridges (often <10 m wide and locally referred to as hogbacks), steep slopes (often >50%), and narrow ravines. Elevations range from ca. 108 to 185 m. Bedrock is predominantly cherty limestones of the Mississippian System. Tuscaloosa white chert gravels and McNairy Sand (Cretaceous) occur at higher elevations and brown gravels (Tertiary-Quaternary) and silty loess (Pleisto-

cene) veneer some uplands. Patches of gravel and conglomerate frequently are exposed on slopes and ridges. Soils have developed in a variety of parent materials, especially thin loess over gravel and chert, and are mostly infertile and droughty (Harris 1988). Vegetationally, LBL is within the transitional Western Mesophytic Region of Braun (1950) and is characterized by a mixture of flora and vegetation types.

METHODS

Site Selection

Based on the stated objective to characterize the woody strata of the most mature chestnut oak stands in the area, sites were non-randomly selected based on (1) topography and xeric conditions, (2) the presence of numerous and mature chestnut oaks (≥35–45 cm dbh; Franklin and Fralish 1994) and (3) few if any signs of human disturbance. One of the selected sites is in Lyon County, Kentucky; seven are in Trigg County, Kentucky; and two are in Stewart County, Tennessee.

Field Sampling

During summer 1997, each site was floristically surveyed and sampled by three to six (total of 45) permanently-marked 0.04 ha (0.1 acre) plots established along the center of ridges or along mid-slope transects for slopes. Plots were separated minimally by 10 m and were placed well within the forest to avoid edge effects. Within each plot all woody stems (except vines) with a diameter at breast height (dbh) ≥2.54 cm (1 inch) were measured to the nearest 0.25 cm (0.1 inch) and recorded by species. Shrubs and woody seedlings (dbh <2.54 cm) were counted by species within a circular plot of 0.004 ha (0.01 acre) at the center of each 0.04-ha plot; species of *Carya*, *Quercus*, and *Vaccinium* <2.54 cm were not separated because of uncertainty in identification (oaks were separated into the "white oak group" and the "red/black oak group"). Taxa were categorized into three strata based on dbh: canopy (≥10.16 cm), saplings/small trees (2.54 to 10.15 cm), and seedlings/shrubs (<2.54 cm). Taxonomy and nomenclature follow Gleason and Cronquist (1991).

Data Analyses

Presence (percent of stands in which a species occurred) was calculated, and each species was assigned to a presence class (Oosting 1956): 1 (rare, occurring in 1–20% of the stands); 2 (seldom present, 21–40%); 3 (often present, 41–60%); 4 (mostly present, 61–80%); 5 (constantly present, 81–100%). Percentages were compared with normal distributions (Oosting 1956). Richness (Krebs 1985) was determined and compared with published values.

The degree of similarity between stands was calculated with three indices of community similarity, comparing the 45 pairwise combinations for canopy species. These included the Sorenson Index (IS_S) based on presence (Barbour et al. 1987; Mueller-Dombois and Ellenberg 1974) and the Jaccard Index as modified by Ellenberg (IS_E) for percent density and percent basal area (Mueller-Dombois and Ellenberg 1974).

Species diversity was calculated by the Shannon-Wiener Index using the equations from Krebs (1985). This index allowed for comparison with published index values from various regions of the Eastern Deciduous Forest.

Community structure was derived from average dbh, density, relative density, basal area, relative basal area, frequency, and relative frequency for species in the canopy and sapling/small tree stratum. Summation of the relative values gave an importance value (IV) with a maximum of 300 (Barbour et al. 1987). Density, relative density, frequency, relative frequency, and importance value (IV maximum of 200) were used to characterize the woody seedling stratum.

RESULTS AND DISCUSSION

Presence and Richness

Nine species (31%), including *Amelanchier arborea, Carya glabra, Cornus florida, Juniperus virginiana, Oxydendrum arboreum, Quercus prinus, Q. velutina, Sassafras albidum,* and *Vaccinium arboreum,* occurred in presence class 5 (9 or 10 stands). Six species (21%), including *Carya tomentosa, Diospyros virginiana, Nyssa sylvatica, Quercus alba, Q. marilandica,* and *Q. stellata,* were in class 4 (7 or 8 stands). Two species (7%), *Prunus sero-*

tina and *Ulmus alata,* were in class 3 (5 or 6 stands). Class 2 (3 or 4 stands) included 3 species (10%) and class 1 (1 or 2 stands) nine species (31%). Normally, class 1 (rare) will include about 56% of the species and classes 3, 4, and 5 combined about 28%. Here, only 31% of the taxa occurred in class 1, and classes 3, 4, and 5 accounted for 60%, indicating a community with a higher than normal percentage of species that are regularly to constantly present in representative stands and fewer than normal percentage of species that are not regularly encountered.

Richness per stand for all taxa ranged from 12 to 22, average 16.5, total 29. For the shrub/seedling stratum, the range was 9 to 13 (taxa of *Carya, Quercus,* and *Vaccinium* not differentiated), average 10.5, total 20; and for the sapling/small tree stratum, the range was 10 to 19, average 14.4, total 25. For canopy species, richness ranged from 9 to 13, average 11.2, total 16. This total is comparable for chestnut oak communities outside of LBL, e.g., 15 for stands on the Western Highland Rim south of LBL (Wheat and Dimmick 1987) and 15 for the dry ridge communities just east of LBL (Chester et al. 1995). Elsewhere, Condley (1984) found species numbers to vary from 6 to 17 on ridgetop chestnut oak communities of the Ridge and Valley Province from Alabama to Vermont.

Community Similarity Indices

Community similarity indices may range from 0 (complete difference) to 100 (identity) and any two plots with a value ≥50 represent the same association (Barbour et al. 1987). Our Sorenson Index (IS_S), ranged from 25 to 89 with a mean of 66; 6 of the 45 comparisons were below 50. However, stand similarity is not only a function of species in common but also the amount of each species present (Mueller-Dombois and Ellenberg 1974). Jaccard's Index as modified by Ellenberg (IS_E) for percent density ranged from 59 to 95 with an average of 86. For percent basal area, IS_E ranged from 75 to 98 with an average of 92. Thus, some site variation occurs in canopy floristic composition but there is close similarity in percent density and basal area.

Diversity Indices

The Shannon-Wiener Diversity Index (H′) is based on two components of diversity: (1) number of species and (2) equitability or evenness of allotment of individuals among species (Krebs 1985). Values may range from 0 for a community of one species to >7 for very rich communities (Barbour et al. 1987). In eastern North America, H′ values for Braun's nine regions of the Eastern Deciduous Forest ranged from 1.84 in the Beech-Maple Region to 3.40 in the diverse Mixed Mesophytic Region (Monk 1967). Within the Interior Low Plateaus, values ranged from 2.49 to 3.09. Our H′ values of 2.79 (canopy), 3.43 (saplings/small trees), and 2.33 (seedlings/shrubs) generally are within the range for the area. The increase in H′ from seedlings to saplings/small trees and from seedlings to canopy are indicators that these forest stands are mature or are in late successional stages (Monk 1967).

Community Structure

A total of 2,017 stems with dbh ≥2.54 cm representing 20 genera and 26 species was measured. About half of these stems (1,007, 49.93%) were in the 2.54 to 10.15 cm dbh size class; 1,010 stems (50.07%) had a dbh ≥10.16 cm. The average diameter of all stems was 15.10 cm; for stems ≥10.16 cm, the average was 25.37 cm. The largest trees sampled were individuals of *Q. prinus* (dbh in cm of 94.7, 81.8, 8 specimens 71 to 81, 4 specimens 61 to 70). Counts of annual rings in 10 freshly cut chestnut oak stumps from a stand adjacent to one of our sampling sites in Stewart County, Tennessee, showed that trees in the dbh range of 60 to 65 cm were over 100 years old.

The canopy included 16 species within 10 genera (Table 1). Density was 548.9 stems/ha and basal area 34.6 m^2/ha. Dominance was clearly assumed by *Q. prinus* (59.2% of IV). A second and much lower tier of contributing species included *Oxydendrum arboreum* (8.1%), *Q. velutina* (6.7), *Carya glabra* (5.1), *Q. marilandica* (4.5), *Q. stellata* (4.2), and *Q. alba* (3.6). These 7/16 species accounted for 91.4% of IV. At the generic level, *Quercus* (6 species) accounted for almost 80% of IV. No species with canopy-size individuals were found in floristic surveys that were not found in the sampling plots.

The sapling/small tree stratum included 25 species representing 19 genera (Table 2). Density was 547 stems/ha and basal area 1.3 m^2/ha. This stratum also was dominated by *Q.*

Table 1. Species composition and structure of the canopy layer (≥10.16 cm dbh) in 10 xeric-site chestnut oak forests, Northwestern Highland Rim, Kentucky and Tennessee.

Taxa	No. stems	Avg. dbh (cm)	Density (No./ha)	Rel. density	Basal area (m^2/ha)	Rel. basal area	No. plots	Freq.	Rel. freq.	I.V. (300)	% of I.V.
Quercus prinus	699	28.24	379.89	69.21	28.676	82.84	45	100.00	25.42	177.48	59.159
Oxydendrum arboreum	85	14.09	46.20	8.42	0.827	2.39	24	53.33	13.56	24.36	8.122
Quercus velutina	43	24.63	23.37	4.26	1.326	3.83	21	46.67	11.86	19.95	6.651
Carya glabra	55	17.24	29.89	5.45	0.851	2.46	13	28.89	7.34	15.25	5.083
Quercus marilandica	32	20.44	17.39	3.17	0.682	1.97	15	33.33	8.47	13.61	4.538
Quercus stellata	27	22.63	14.67	2.67	0.720	2.08	14	31.11	7.91	12.66	4.221
Quercus alba	21	28.93	11.41	2.08	0.869	2.51	11	24.44	6.21	10.80	3.601
Cornus florida	11	11.91	5.98	1.09	0.067	0.19	9	20.00	5.08	6.37	2.122
Nyssa sylvatica	12	20.37	6.52	1.19	0.246	0.71	7	15.56	3.95	5.85	1.951
Quercus coccinea	7	17.29	3.80	0.69	0.103	0.30	5	11.11	2.82	3.82	1.272
Carya tomentosa	8	20.09	4.35	0.79	0.153	0.44	3	6.67	1.69	2.93	0.976
Juniperus virginiana	3	11.76	1.63	0.30	0.018	0.05	3	6.67	1.69	2.04	0.681
Sassafras albidum	3	11.17	1.63	0.30	0.011	0.03	3	6.67	1.69	2.02	0.675
Fraxinus americana	2	15.24	1.09	0.20	0.021	0.06	2	4.44	1.13	1.39	0.463
Liquidambar styraciflua	1	29.97	0.54	0.10	0.039	0.11	1	2.22	0.56	0.78	0.259
Ostrya virginiana	1	11.68	0.54	0.10	0.006	0.02	1	2.22	0.56	0.68	0.227
Totals	1010	25.35	548.90	100.00	34.615	100.00			100.00	300.00	100.000

prinus (16.5% of IV). Other dominants were *Vaccinium arboreum* (14.2), *Carya glabra* (12.1), *Oxydendrum arboreum* (10.1), *Cornus florida* (8.9), and *Sassafras albidum* (7.5). These 6/25 taxa accounted for almost 70% of IV. At the generic level, the six species of *Quercus* accounted for 29.9% of IV and two species of *Carya* for 14.2%. Only one taxon,

Table 2. Species composition and structure of the sapling/small tree layer (2.54–10.15 cm dbh) in 10 xeric-site chestnut oak forests, Northwestern Highland Rim, Kentucky and Tennessee.

Taxa	No. stems	Avg. dbh (cm)	Density (No./ha)	Rel. density	Basal area (m^2/ha)	Rel. basal area	No. plots	Freq.	Rel. freq.	I.V. (300)	% of I.V.
Quercus prinus	151	5.97	82.07	15.00	0.263	20.15	39	86.67	14.50	49.65	16.549
Vaccinium arboreum	249	3.28	135.33	24.73	0.125	9.58	22	48.89	8.18	42.48	14.161
Carya glabra	134	5.21	72.83	13.31	0.180	13.79	25	55.56	9.29	36.39	12.131
Oxydendrum arboreum	102	5.28	55.43	10.13	0.147	11.26	24	53.33	8.92	30.32	10.105
Cornus florida	71	5.99	38.59	7.05	0.122	9.35	28	62.22	10.41	26.81	8.936
Sassafras albidum	79	4.37	42.93	7.85	0.079	6.05	23	51.11	8.55	22.45	7.483
Quercus velutina	27	5.23	14.67	2.68	0.038	2.91	18	40.00	6.69	12.28	4.095
Quercus alba	7	5.97	3.80	0.70	0.121	9.27	6	13.33	2.23	12.20	4.066
Amelanchier arborea	38	4.27	20.65	3.77	0.035	2.68	12	26.67	4.46	10.92	3.639
Nyssa sylvatica	26	5.49	14.13	2.58	0.038	2.91	12	26.67	4.46	9.95	3.318
Quercus marilandica	17	5.59	9.24	1.69	0.026	1.99	14	31.11	5.20	8.88	2.962
Ulmus alata	36	4.39	19.57	3.57	0.035	2.68	7	15.56	2.60	8.86	2.953
Juniperus virginiana	16	4.65	8.70	1.59	0.017	1.30	11	24.44	4.09	6.98	2.327
Carya tomentosa	14	5.79	7.61	1.39	0.024	1.84	8	17.78	2.97	6.20	2.068
Quercus stellata	12	6.60	6.52	1.19	0.024	1.84	6	13.33	2.23	5.26	1.754
Diospyros virginiana	7	3.23	3.80	0.70	0.003	0.23	3	6.67	1.12	2.04	0.680
Acer saccharum	6	3.89	3.26	0.60	0.005	0.38	2	4.44	0.74	1.72	0.574
Quercus coccinea	3	5.66	1.63	0.30	0.004	0.31	2	4.44	0.74	1.35	0.449
Cercis canadensis	4	3.30	2.17	0.40	0.002	0.15	1	2.22	0.37	0.92	0.307
Ostrya virginiana	3	4.22	1.63	0.30	0.003	0.23	1	2.22	0.37	0.90	0.300
Celtis laevigata	1	9.91	0.54	0.10	0.004	0.31	1	2.22	0.37	0.78	0.259
Prunus serotina	1	9.65	0.54	0.10	0.004	0.31	1	2.22	0.37	0.78	0.259
Tilia heterophylla	1	9.14	0.54	0.10	0.004	0.31	1	2.22	0.37	0.78	0.259
Liquidambar styraciflua	1	3.81	0.54	0.10	0.001	0.08	1	2.22	0.37	0.55	0.183
Robinia pseudoacacia	1	4.06	0.54	0.10	0.001	0.08	1	2.22	0.37	0.55	0.183
Totals	1007	4.80	547.28	100.00	1.305	100.00			100.00	300.00	100.000

Table 3. Species composition and structure of the shrub/woody seedling layer (<2.54 cm dbh) in 10 xeric-site chestnut oak forests, Northwestern Highland Rim, Kentucky and Tennessee.

Taxa	No. stems	Density (No./ha)	Rel. density	No. plots	Freq.	Rel. freq.	I.V. (200)	% of I.V.
Quercus/whites	1430	7945.08	33.65	45	100.00	16.67	50.32	25.16
Vaccinium spp.	1477	8206.21	34.76	37	82.22	13.70	48.46	24.23
Quercus/blks.-reds	482	2677.99	11.34	44	97.78	16.30	27.64	13.82
Sassafras albidum	450	2500.20	10.59	29	64.44	10.74	21.33	10.67
Carya spp.	146	811.18	3.44	32	71.11	11.85	15.29	7.65
Amelanchier arborea	123	683.39	2.89	25	55.56	9.26	12.15	6.08
Diospyros virginiana	24	133.34	0.56	12	26.67	4.45	5.01	2.51
Oxydendrum arboreum	45	250.02	1.06	10	22.22	3.70	4.76	2.38
Nyssa sylvatica	27	150.01	0.64	8	17.78	2.96	3.60	1.80
Prunus serotina	8	44.45	0.19	6	13.33	2.22	2.41	1.21
Ulmus alata	16	88.90	0.38	5	11.11	1.85	2.23	1.12
Cornus florida	7	38.89	0.16	4	8.89	1.48	1.64	0.82
Juniperus virginiana	4	22.22	0.09	4	8.89	1.48	1.57	0.79
Cercis canadensis	3	16.67	0.07	2	4.44	0.74	0.81	0.41
Acer saccharum	2	11.11	0.05	2	4.44	0.74	0.79	0.40
Ceanothus americanus	1	5.56	0.02	1	2.22	0.37	0.39	0.20
Fraxinus americana	1	5.56	0.02	1	2.22	0.37	0.39	0.20
Liriodendron tulipifera	1	5.56	0.02	1	2.22	0.37	0.39	0.20
Rhus copallina	1	5.56	0.02	1	2.22	0.37	0.39	0.20
Robinia pseudoacacia	1	5.56	0.02	1	2.22	0.37	0.39	0.20
Total	4249	23,607.46	100.00			100.00	200.00	100.05

Malus angustifolia (crabapple), was found in floristic studies that did not appear in sampling plots.

The shrub/woody seedling stratum included 20 taxa or taxa groups (*Carya, Quercus, Vaccinium*) (Table 3); 4,249 stems were counted, giving a density of 23,607 stems/ha. Dominants included *Quercus*-white oak group (25.16% of IV), *Vaccinium* spp. (*V. arboreum* mostly with some *V. pallidum, V. stamineum*; rarely *Gaylussacia baccata*) (24.23%), *Quercus*-black/red oak group (13.82%), and *Sassafras albidum* (10.67%); these taxa accounted for 74% of IV. Taxa limited to this stratum were *Ceanothus americanus, Liriodendron tulipifera,* and *Rhus copallina.*

Successional Status and Stability

Numerous recent literature accounts suggest (1) that fire was a major factor in maintaining oak dominance in eastern United States before European settlement and (2) that many current oak forests in eastern North America are being replaced by other, mostly more mesophytic species (Abrams 1992, 1994, 1996; Fralish et al. 1991; Lorimer 1989; McGee 1986; Olson 1996; Parker 1989). Lorimer (1989) summarized the principal causes of oak regeneration failure as the sluggish growth of oak seedlings, allowing them to be over-topped by other species, primarily because a lack of fire allows shade-tolerant competitors to thrive. In addition, the dramatic rise in numbers of white-tailed deer (*Odocoileus virginianus*), which selectively browse oak seedlings, may exacerbate the oak regeneration problem (Abrams 1996). Thus, most oak-dominated forests at the time of settlement were successional in nature or a disturbance climax maintained by fire. An exception may be those on xeric or nutrient-poor sites that are an edaphic climax (Abrams 1992, 1994). Thus, most literature supports the conclusion of Abrams (1996) that fire exclusion this century has facilitated the invasion of most oak understories by later successional species, which are over-topping seedlings, and that a major loss of oak dominance should be anticipated in the next century.

The Northwestern Highland Rim clearly is an area where fire and other factors have been important in current vegetation patterns and the successional nature of most oak forests in the absence of fire is documented (Fralish et al. 1993; Franklin et al. 1993). Annual burning by Native Americans was apparently practiced throughout the area (Baskin et al. 1994; Chester et al. 1997; Franklin 1994; Olson 1996).

Lightning-caused fires in some cases (Olson 1996) and large herds of herbivores (bison, deer, elk) had some impact through trampling and grazing (Chester et al. 1997; Franklin 1994). After settlement, woodland fires continued to be commonplace in the LBL region for a number of reasons, including land-clearing, controlling "broomsedge" (*Andropogon* spp.), and hunting. In addition, wildfires frequently resulted from iron manufacturing (charcoal production and blast furnaces), secreted whiskey stills, "plantbeds" for tobacco seedlings (woodland areas burned for weed control in which tobacco seedlings were then grown), and numerous others (Schibig and Chester 1988; Franklin 1994; Wallace 1988, 1992). However, over the past 100 years fires were not an annual occurrence in many woodlands because the farmers in the mostly agrarian region recognized the importance of forest fire prevention. Fires have been virtually absent since the early 1960s.

Since the onset of fire suppression the oak-dominated woodlands have apparently undergone significant changes. Extensive studies in LBL, summarized by Fralish et al. (1993) and Franklin et al. (1993), pointed out that most mesic sites currently dominated by oaks are being replaced by mesophytic species, notably sugar maple. Upland, xeric landscapes, as studied here, that were more open (Olson 1996) and may have been savanna and/or barren-like and dominated by prairie grasses with only scattered oaks "have succeeded to closed forest with a depleted herbaceous layer" (Franklin 1994; Franklin and Fralish 1994).

The question of stability in the xeric-site chestnut oak stands is not clear. Wheat and Dimmick (1997), referencing stands on the Western Rim in Tennessee, noted that "the importance of chestnut oak in all forest strata suggests stability in this community"; Fralish and Crooks (1988, 1989) expected chestnut oak to dominate such sites indefinitely. Certainly, the importance of chestnut oak in all strata, and the scarcity of sugar maple and other mesophytic species in the understory, as revealed in this study, suggest compositional stability. Yet Abrams (1992, 1994) pointed out that oaks are being replaced even in some communities containing a substantial number of oak seedlings. Also, Abrams (1996) observed that while oak forests on xeric and nutrient-poor sites (as in our study) may represent an edaphic climax, "they may alternatively be exhibiting slow rates of successional replacement and thus not have long-term stability in the absence of fire." Our permanent plots in 10 such stands will provide an excellent opportunity for us (and others) to document compositional changes in publicly-owned, fire-controlled stands over an extended time frame.

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INDEX TO VOLUME 59

Compiled by Varley Wiedeman

PUBLICATION

John Uri Lloyd: The Great American Eclectic, by Michael A. Flannery, has just been published. A hard-cover book of 234 pages, this biography covers the life of an adopted son of Kentucky who rose from humble origins in Florence, Boone County, to become a pharmaceutical manufacturer and researcher of international renown. In addition, Lloyd was the leading founder of the Cincinnati-based library of botany, horticulture, and pharmacognosy that bears his name. The book, fully indexed, includes five appendices and 14 pages of illustrations. It is available from Southern Illinois University Press, P.O. Box 3697, Carbondale, IL 62902; ISBN 0-8093-2167-X; price $34.95 plus $3.50 shipping. Phone orders: (618) 453-2281.

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ARTICLES